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A CONTRAST EQUALITY PHOTOMETER.

By A. H. Pfund.

SEVERAL years ago the writer described a simple equality-photometer[1] which has been used with success by several investigators. Recently it was found possible to modify the design of the instrument so as to introduce also the principle of contrast and thus to attain (theoretically) double the sensibility of the perfect equality-photometer.

The plan of the photometer-head is shown in Fig. 1 where *AA* represents a plate of brass set diagonally in a small wooden box, 3 × 3 × 3 cm. An elliptically shaped hole is cut in the center of the brass plate, the axes being 10 and 7 mm. A mirror, consisting of a piece of platinized plate-glass (*B*), covers one half of the opening, the vertical edge of the glass coinciding with the mirror axis. By viewing this system through a tube *T* containing a lens which magnifies 3 diameters, a circular field, divided centrally by a perfect edge, is seen. This arrangement constitutes the equality-photometer previously described.

In order to increase the sensibility of the instrument, a piece of smoked or neutral-tint glass was ground down to a very thin optical wedge whose transmission near the thin edge was greater by about 2 per cent. than at the thick edge. After cutting the glass in two so as to procure two identical wedges, the ground surfaces were cemented to pieces of clear glass by means of Canada balsam—thus avoiding the necessity of polishing. These wedges were then mounted at *C* and *C'* and were so adjusted that their density gradients, though vertical, were reversed. Upon mounting this photometer-head and establishing a photometric balance an appearance, similar to that shown in Fig. 2, was presented. In this illustration the density gradient was made large purposely so as to bring out the principle involved. It is evident that photometric balance has been established when equality exists at the center of the

[1] Johns Hopkins University Circular (1906), p. 20.

field and equal contrast in the upper and lower portions. Without going into details it may be shown that if (for example) the eye is capable of detecting a minimum intensity difference of 2 per cent. and if the excess of transmission through the thin part of the wedge be 1 per cent., then the accuracy of setting will be double that obtainable by means of an equality photometer.[1]

Before discussing the results obtained, it may not be out of place to describe the method employed in preparing the mirror B. A piece of plate-glass of the approximate dimensions $25 \times 15 \times 1$ mm. is scratched, as shown in Fig. 3, by means of a steel-wheel glass-cutter, and is then broken in two along the dotted line. The portions not touched by the steel-wheel present perfect edges. These plates are subsequently covered cathodically by a hard, highly reflecting layer of platinum and thus two plates, either of which may be used as mirror B, are obtained. It is needless to add that subsequent polishing is liable to destroy the perfection of the edge.

A typical series of measurements is recorded below. The comparison of a 50-watt tungsten lamp against a carbon lamp of almost equal candle-power was carried out. It will be pointed out later that a striking feature of this type of photometer is that the eye depends upon difference of contrast and disregards, to a very marked extent, differences of color. In order to accentuate the contrast in color between the tungsten and carbon lamps, a sheet of clear glass of slightly greenish hue was placed between the tungsten lamp and the photometer head. The lamps were about 200 cm. apart and the photometer head, when in position of balance, was nearly half-way between them.

Distance from Tungsten Lamp to Photometer.	Residuals.	
102.08 cm.	+.02 cm.	
102.26	+.20	
102.00	−.04	
102.13	+.07	
101.96	−.10	
102.11	+.05	Average deviation from mean setting 9.4 parts in 10,000 or < .01 per cent.
101.91	−.15	
101.98	−.08	
101.95	−.11	
102.20	+.14	
Mean 102.06		

In view of the circumstance that the lamps were permanently separated by a distance of 2 meters the error of setting the movable photometer-head is but one fourth of the error in candle-power measurement—hence,

[1] After the completion of this work (Jan., 1914) the writer was told by Dr. E. P. Hyde that he had constructed a photometer involving a similar principle. He placed opposed wedges in front of a Lummer-Brodhun contrast photometer and made final settings by obtaining equality of contrast at the edge of one of the trapezoids.—The work was never published.

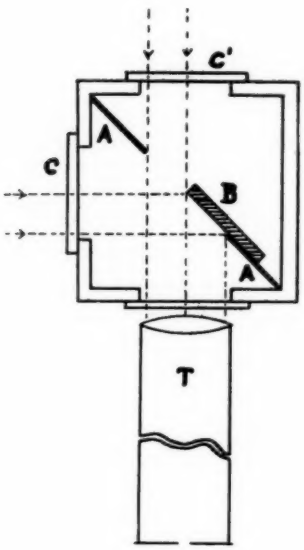

Fig. 1.

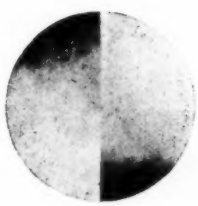

Fig. 2.

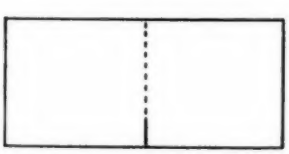

Fig. 3.

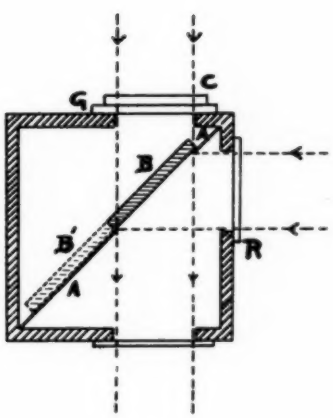

Fig. 4.

A. H. PFUND.

while the error of setting was about 0.1 per cent. the error in c. p. measurement is 0.38 per cent.—The optical wedges used possessed too high a density gradient, hence the ideal conditions, which may be realized with care, were not fulfilled. It is shown, nevertheless, that even though an appreciable color difference exist between the sources, a very fair degree of accuracy is attainable by means of this photometer.

In the course of the work it became evident that the instrument could be used in the comparison of the intensities of colored light-sources. For a successful comparison of such sources it is necessary to increase the density gradient as the difference in color between the light-sources increases for the eye depends largely upon the equality of contrast and not upon a judgment of equality of luminosity. If a red and a green source are to be compared and equality of contrast has been established it is found that the eye has introduced a second (rather diffuse) line into the field of view. This subjective line intersects with the permanent vertical edge at an angle, the point of intersection being at the center of the field of view when a balance is established. By viewing Fig. 1 this subjective line, which divides the field of view into four sectors, may be readily observed. The two criteria of balance, *i. e.*, equality of contrast and central intersection of the two lines, supplement one another and thus increase the accuracy of setting.

This arrangement was tested by inserting a plate of glass covered with green-stained gelatine in front of the tungsten lamp and a similar red-stained plate in front of the carbon lamp. The distance from each source to the usual plaster of paris diffusing screen was very nearly 51 cm. A typical series of settings is given below:

Distance from Lamp to Diffusing Screen.	Residuals.	
Mean 102.06		
51.4 cm.	+0.00	
51.5	+0.1	
50.7	−0.7	
51.3	−0.1	
51.5	+0.1	
50.7	−0.7	
51.2	−0.2	
51.4*	0.0	Average deviation from mean setting 4.8 parts in 1,000.
51.6	+0.2	
51.5	+0.1	
51.2	−0.2	
51.7	+0.3	
51.3	−0.1	
51.7*	+0.3	
51.8	+0.4	
51.1	−0.3	
Mean 51.4		

The stars opposite the 8th and 14th setting indicate that 10 minutes were allowed to elapse before making the next setting in order to determine whether or not fatigue had much influence on the accuracy of setting. It will be noted that even under these extreme conditions of color difference the average deviation from the mean setting is but 4.8 parts in 1,000, whereas the average deviation from the mean candle-power is 1.9 parts in 100 or nearly 2 per cent.

After the completion of this series, Mr. Enoch Karrer, who had had no experience with this instrument, was called in. He succeeded at once in making settings which agreed, within the limits of accuracy, with those previously obtained by the writer. The wedges were then removed and a comparison of the same (red and green) light sources was attempted. The task seemed hopeless as all criteria had disappeared and recourse had to be taken to a very questionable "judgment" of equality.

An attempt was next made to use the optical wedge also in the construction of a flicker-photometer. This instrument, as shown in Fig. 4, consists of the usual brass plate AA' with elliptical aperture behind which a platinized mirror is caused to oscillate. The former red and green plates are attached to the photometer-head at R and G. When the mirror is in the position B, the entire field of view appears green and conversely, when the mirror is in the position B', the entire field of view appears red. A single optical wedge with its density gradient vertical was inserted at C. It is evident that the criterion for equal intensity is no longer disappearance of flicker over the entire field, but equality of flicker in the upper and lower portions and disappearance of flicker in the center. Surprisingly accurate settings could be made with this device—in fact, when red and green sources were compared, the average deviation from the mean candle-power was but 0.6 per cent.

In order to determine whether or not the flicker could actually be made to disappear over the entire field of view when the wedge was removed, further experiments were carried out on this point. It was noted that, with this arrangement, the flicker could not be made to disappear. As one of the sources was slowly moved up toward the position of equality the flicker first disappeared in (say) the right portion of the field of view but persisted in the left. A still closer approach of the source brought about equality of flicker on the right and left and absence of flicker in the middle—a condition which has been considered as the criterion for photometric balance. Thus it is evident that, even without the use of an optical wedge, the condition of equality of flicker may be realized. The writer assured himself that there was no asymmetry in the instru-

ment capable of accounting for the above effect—and, up to the present, no satisfactory explanation has been found.

The preceding is to be looked upon as a preliminary publication, for much remains to be done in defining the various conditions of maximum sensibility of the several photometric appliances. This work is to be taken up and extended in the near future.

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THE HALL EFFECT AND ALLIED PHENOMENA IN SILICON.

BY O. E. BUCKLEY.

THE Hall effect in silicon was first measured by Miss Wick[1] who obtained for the coefficient of the effect, R, the values, -120 for silicon 99 per cent. pure and -28 for silicon 96 per cent. pure. Miss Wick also made measurements of the thermal E.M.F. and the resistance of silicon.

Later Zimmerman[2] found the direction of the thermal E.M.F. of several specimens of silicon against copper to be opposite in direction to that which Miss Wick had determined although some specimens gave a thermal E.M.F. in the same direction as that which she had found. This peculiarity in the behavior of silicon led A. W. Smith[3] to make investigations of the Hall effect in these specimens. For four of his specimens he obtained values of R varying from $+40$ to $+60$. In all of these plates the direction of the thermal E.M.F. was such as to send a current from copper to silicon across the hot junction. In a fifth specimen he found $R = -20$ and in this specimen the thermal E.M.F. was in the opposite direction to that in the plates with the positive Hall effect.

Koenigsberger and Gottstein[4] measured the Hall effect in silicon containing 5 per cent. iron and found by direct measurement $R = +24.5$. They apply two corrections to this value, one for the error due to the Ettinghausen effect and one to change the adiabatic effect to an isothermal effect, the final result being $R = +110$.

Gottstein[5] also measured the Nernst effect in two pieces of silicon and found by direct measurement the values .0132 and .0116 for the coefficient of the effect, Q. He applies corrections as he did for the Hall effect and arrives at the values .0333 and .028. He does not indicate the direction of the effect.

The thermal E.M.F. of silicon against copper has been found by several observers to vary from $+.5$ to $-.5$ millivolt per degree. The

[1] PHYS. REV., 27, p. 76, 1908.
[2] Trans. Amer. Electro-chem. Soc., 15, p. 395, 1909.
[3] PHYS. REV., 30, p. 1, 1910.
[4] Phys. Zeit., 14, p. 232, 1913.
[5] Ann. der Phys., 43, p. 1079, 1914.

reversal of the thermo-electric behavior has been investigated by Fischer, Lepsius and Baerwind.[1] From their experiments they concluded that the reversal was due to the presence of SiO_2 in the silicon.

Measurements of the resistance of silicon have been made by several observers with widely varying results. Miss Wick[2] found values for the resistance in ohms per c.c. varying from .034 to .080 in the different specimens which she measured. Some of Miss Wick's specimens showed a steady decrease of resistance with rising temperature while other specimens showed minima at about 200° C. Koenigsberger and Schilling[3] with very pure silicon obtained the value .0885 at 15° C. The resistance-temperature curve of this specimen contained two discontinuities.

A list of several physical constants of silicon has been published by Zimmerman.[4] The thermal conductivity and Thomson coefficient have been measured by Koenigsberger and Weiss.[5] The Peltier coefficient has been measured by Gottstein.[6] Koenigsberger[7] has given a discussion of the electrical properties of silicon and similarly behaving substances with reference to the electron theory.

In most of the work on silicon and similar substances measurements of various electrical properties have been made with different specimens. Since different specimens, sometimes even if cut from the same piece, may vary widely in their electrical properties it is important that measurements of different properties be made with the same specimens.

This research was undertaken to determine whether the wide variations and reversal of sign of the Hall effect in various specimens of silicon were accompanied by marked variations in the Nernst effect and resistance. The temperature coefficients of these quantities were also measured to see if any apparent connection existed among them. For this purpose four specimens of silicon of widely varying degrees of purity were used. These specimens were donated by the Carborundum Company, who also kindly furnished analyses. The analyses of the specimens showed impurities as follows:

Unfortunately Plate I. was not very compact. It contained small blow holes, a few of which were over half a millimeter in diameter and over a millimeter long. These holes undoubtedly affected the results with this specimen seriously. Plate III. contained a few small pin holes, not more than four or five to the square centimeter, and of small depth.

[1] Phys. Zeit., 14, p. 439, 1913.
[2] PHYS. REV., 27, p. 11, 1908.
[3] Ann. der Phys., 32, p. 179, 1910.
[4] Trans. Amer. Electro-chem. Soc., 15, p. 395, 1909.
[5] Ann. der Phys., 35, p. 1, 1911.
[6] Ann. der Phys., 43, p. 1079, 1914.
[7] Jahrbuch der Rad. u. Elek., 11, p. 84, 1914.

Specimen.	Fe, Per Cent.	Al, Per Cent.	Si (by Difference), Per Cent.
I.....	0.35	0.19	99.46
II.....	3.50	0.23	96.27
III.....	3.38	2.55	94.07
IV.....	7.27	3.35	89.38

Plates II. and IV. were quite compact. None of the specimens contained any surfaces of separation.

Plates were sawed from irregularly shaped blocks of silicon to the shape shown in Fig. 1 by means of a vulcanite carborundum wheel which was arranged to run in a trough containing water and fine carborundum powder. On account of the limits set by the blocks from which the plates were cut, the dimensions of the plates varied somewhat with the different specimens. The approximate dimensions were, length 4 cm., width 1.8 cm., thickness 0.5 cm., length of side arms from 0.8 cm. to 2.4 cm. In every case the side arms were made as long as possible.

Fig. 1.

The ends of the plates and the ends of the side arms were heavily copper plated. Wires soldered to the copper on the ends of the plate served for leads for the current through the plate. Wires soldered to the copper on the ends of the side arms led to a potentiometer which was used to measure the Hall E.M.F. Near each end of the plate a very narrow copper band was plated onto the silicon completely encircling it. These bands served as contacts to measure the resistance by the fall of potential method. In making measurements of the Hall effect and resistance at various temperatures the plate under test was placed in a double-walled copper vessel held between the poles of a large Weiss electro-magnet. The desired temperature was obtained by circulating water between the walls of the vessel. For the highest temperature steam was used. Readings were taken at four different temperatures between 0° and 100°.

The pole pieces of the magnet were 10 cm. in diameter and were placed 2.2 cm. apart. Over the area of the plate the field was practically uniform. For most of the measurements of the Hall effect a field of about 9,000 gauss was used.

The difference of potential between the side arms and between the resistance contacts was measured by means of a low resistance potentiometer and a sensitive D'Arsonval galvanometer with small period. In making measurements of the Hall effect a current through the plate of about .16 ampere was generally used. A larger current caused objectionable thermal disturbances. The effect of any gradual temperature

change was cancelled out by taking a series of readings at equal time intervals, reversing the field after each reading.

The coefficient of the Hall effect, R, is defined by the equation

$$E = RiwH,$$

where E is the Hall E.M.F., i, the current density, w the width of the plate, and H, the intensity of the magnetic field. If I, the whole current in the plate is used in place of i, the current density, the equation may be written

$$R = \frac{Et}{IH},$$

where t is the thickness of the plate.

Plate II. was found to have a negative Hall effect while the other three plates had the positive Hall effect. The values obtained for the coefficient, R, are plotted in Fig. 2. The negative values for Plate II. are plotted as positive.

The resistances of the same plates were measured at various temperatures by comparing the fall of potential through the plate to that through a standard resistance connected in series with it. The fall of potential was measured by connecting the potentiometer to the two copper bands placed near the ends of the silicon plate. Measurements of resistance were made while the plate was held in position for measuring the Hall effect. This arrangement also permitted making a test of the effect of the magnetic field on the resistance of the silicon. No effect

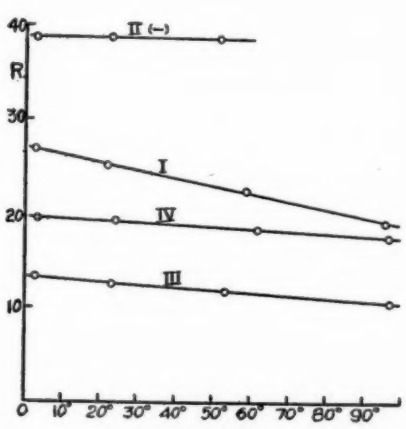

Fig. 2.

Variation of Hall Effect with Temperature.

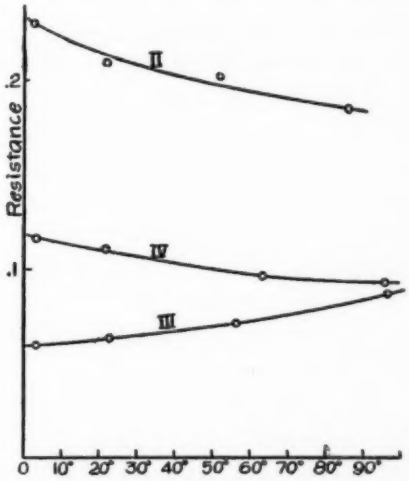

Fig. 3.

Variation of Resistance with Temperature.

could be observed and the change of resistance in a magnetic field of 10,000 gauss was shown to be less than 0.05 per cent.

In attempting to measure the resistance of Plate I. great difficulty was experienced especially at the higher temperatures. No steady reading could be obtained at the higher temperatures and the apparent resistance at room temperature would be found to have changed after heating and cooling. This was probably due to varying contact resistance at the ends of the plate and consequent deflection of the current flow lines. The results obtained for Plate I. were so erratic that no definite value of the resistance can be given. The same difficulty was experienced to a less degree with Plate II. and the value of its resistance at the highest temperature is doubtful. The other two plates gave results which could be repeated.

The values obtained for the specific resistances of the different specimens are plotted in Fig. 3. No correction has been made for the influence of the side arms on the resistance.

Fig. 4 shows the arrangement of apparatus used in making measurements of the Nernst effect. The copper plating on the ends of the silicon plates was ground to fit the grooves in the ends of the copper

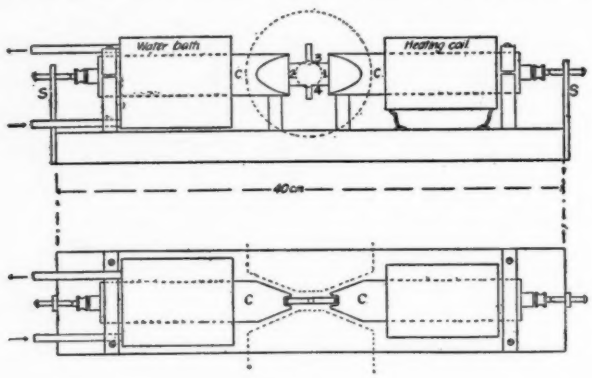

Fig. 4.

bars, *C*. The bars were pressed together against the plate by stiff steel springs, *S*. These bars served both as heat and electrical conductors. For the sake of insuring more uniform contact for heat flow thin tin foil was placed between the copper plating on the ends of the silicon plate and the copper bar.

One of the copper bars was surrounded by a heating coil of nichrome ribbon insulated from the copper by thin asbestos paper. The heating coil was covered with asbestos paper and a clay cylinder to prevent loss of heat. The other copper bar was provided with a water bath through which water at the desired temperature was circulated. In order to make as uniform a temperature gradient as possible and to prevent thermal disturbances the silicon was covered with two layers of wool felt.

Temperatures were measured by means of copper-advance thermojunctions placed at positions 1, 2, 3 and 4 as indicated in Fig. 4. Each junction was fastened to one side of a small fiber cube and pressed against the silicon by a stiff brass spring. The junctions in positions 1 and 2 were separated from the silicon by thin sheets of mica not over .01 mm. thick. This was found necessary on account of the difficulty in placing the wires exactly parallel to equal temperature lines.

Readings of the Nernst effect were taken at intervals of 30 seconds, the magnetic field being reversed after each reading. By leaving the field on continuously except for the time required for reversal, errors due to the effect of the magnetic field on the E.M.F. of the copper-silicon junctions or to the effect of the magnetic field on the heat current in the plate were avoided. One half the observed change of potential difference between the side arms on reversing the field was taken as the Nernst E.M.F. Correction was made for the non-uniformity of the magnetic field across the plate necessitated by the small area of the pole face.

Measurements of the Nernst E.M.F. were taken with varying magnetic field and for several different temperatures with each plate. In every case the E.M.F. was found to be proportional to the field strength up to the limit of field strength used, about 20,000 gauss.

The coefficient of the Nernst effect, Q, is defined by the equation

$$E = \frac{Qdt}{dx} wH,$$

where dt/dx is the temperature gradient. If we assume that the temperature gradient is uniform and let t_1 and t_2 be the temperatures at junctions 1 and 2 respectively and led d represent the distance apart of those junctions, we may write

$$Q = \frac{Ed}{(t_1 - t_2)wH}.$$

The direction of the Nernst effect was found to be the same in all four of the plates. The values found for the coefficient, Q, are plotted in Fig. 5.

Since the Hall and Nernst effects for silicon are quite large as compared with metals it was expected that the corresponding transverse temperature effects would also be large and possibly measurable by a D'Arsonval galvanometer. However, no positive results for these effects were obtained and all that could be done with this apparatus was to set an upper limit to the values of the coefficients of these effects.

To measure the transverse temperature change the thermojunctions at positions 3 and 4 (Fig. 4) were used. Since they were in contact with

the silicon these junctions could not be used in series but each had to be used separately against a similar junction in ice. Two minutes time was allowed after reversing the field, before making a reading, to allow time for the effect, if any, to develop.

The results obtained varied too widely to set a definite value for the effect or to be sure of its direction. For the sake of setting a safe upper limit twice the observed value is given as an upper limit. This is about equivalent to adding to the observed effect three times the probable error in such a way as to increase the value of the effect. The upper limit set in this way for the Ettinghausen coefficient, P, is $P<3\times10^{-6}$ corresponding to a temperature change of about .02°. Limits of the same order of size were obtained for each of the four plates. Comparison of this value with the values found for other substances shows that it is not surprisingly small and no significance would be attached to it were it not that Gottstein[1] reports a value of P for silicon of 2.65 $\times 10^{-3}$. Such a large effect as that could hardly fail to be detected.

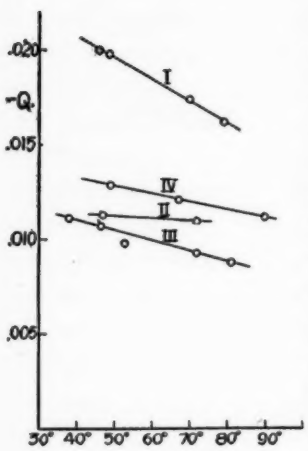

Fig. 5.

Variation of Nernst Effect with Temperature.

Koenigsberger[2] mentions that this effect is so large that it can cause a very large error in the measurement of the Hall effect on account of the transverse change of temperature introducing a thermal E.M.F. We may feel quite sure that this did not cause an error in the measurements reported in this paper, since the use of the side arms would prevent such an effect, and if there were any at all it would be very slow in building up on account of the time required for heat to travel along the side arms to the copper contacts. That there was no such effect was shown by the fact that the galvanometer would come to rest within fifteen seconds after applying the magnetic field.

With a large temperature gradient measurements of the Leduc effect were also attempted. The upper limit set in the same way for the coefficient of the Leduc effect, S, is $S < 5 \times 10^{-8}$ corresponding to a temperature change of about .02°. If this result is compared with the values of S for other substances possessing a large Hall effect it is seen to be very small. Gottstein[3] reports for the Leduc effect in silicon a

[1] Ann. der Phys., 43, p. 1079, 1914.
[2] Jahrbuch der Rad. u. Elek., 11, p. 84, 1914.
[3] Ann. der Phys., 43, p. 1079, 1914.

value of 2.5×10^{-7} which would result in a temperature difference of about .1° under the conditions of this experiment.

The direction of the thermal E.M.F. of the different specimens against copper was tested by connecting one terminal of the galvanometer in series with a high resistance to the copper plating on the silicon plate. The other terminal was connected to a pointed copper rod which was heated by an insulated heating coil wound around it. The point of the rod was then touched to various points on the plate under test. Plates I., III. and IV. gave a deflection always in the direction indicating a current from copper to silicon at the hot junction although the amount of deflection varied greatly with the different points touched. Plate II. gave mostly the opposite direction although occasional points touched gave the same direction as the other three plates. The occasional points in Plate II. which gave the opposite effect were mostly near one end of the plate and were not distributed in any systematic way as far as could be seen.

The following table gives a summary of the results obtained for purposes of comparison.

Plate.	I.	II.	III.	IV.
Hall effect at 50°	+23	−39	+12	+18
Nernst effect at 50°	−.020	−.0113	−.0105	−.013
Specific resistance at 50°		.20	.07	.10
Temp. coef. of Hall effect	−.0031	0	−.0022	−.0011
Temp. coef. of Nernst effect	−.0057	−.0010	−.0053	−.0032
Temp. coef. of resistance		−.0023	+.0047	−.0022
Direction of thermal E.M.F.	+	−	+	+

According to the conclusions which Koenigsberger has drawn from his work the ratio of the resistance to the coefficient of the Hall effect might be expected to be approximately the same for the different specimens. While this happens to be the case at 50° for the three specimens whose resistance was measured, it appears to be entirely accidental since the temperature coefficients of these quantities are not at all in harmony. There appears to be a much closer relation between the temperature coefficients of the Hall and Nernst effects. If the specimens are arranged in order with reference to the temperature coefficients of the Hall effect they are also in order with reference to the temperature coefficients of the Nernst effect. However there is no apparent connection between the magnitudes of these two effects with the different plates.

SUMMARY.

The Hall effect, Nernst effect and resistance of four specimens of silicon have been measured at several different temperatures.

The reversal of the Hall effect, which is connected with a reversal of its thermal E.M.F., is not accompanied by a reversal or peculiarity in size of the Nernst effect nor by a peculiarity in the resistance.

The temperature coefficients of the Hall and Nernst effect are found to be similar but do not bear any apparent relation to the temperature coefficient of resistance.

The extraordinarily large Ettinghausen and Leduc effects in silicon reported by Gottstein are not confirmed.

The change of resistance of silicon in a magnetic field of 10,000 gauss is less than .05 per cent.

The writer is under obligation to Professor Merritt who proposed the investigation and made many helpful suggestions.

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EXPERIMENTS ON THE PRODUCTION AND MEASUREMENT OF HIGH VACUA.

By J. W. Woodrow.

THIS article describes the actual construction of a sensitive Knudsen absolute manometer and explains its use for the measurement of low pressures. An account is also given of some methods employed for obtaining these pressures.

Introduction.

The theory of an absolute manometer, which is independent of the gas to be measured, has been given by Knudsen.[1] However he merely gives data to show that his theory is confirmed by experiment and does not describe the actual construction of such a gauge. A brief outline of the operation of one type of the Knudsen manometer has been given by Angerer,[2] but some difficulty was experienced by the author of this article in trying to make a sensitive gauge according to his instructions. Therefore, as quite a little time has been spent in this laboratory on the construction of a very sensitive gauge which would be at the same time easily made and simple in operation, it was thought that the results of these experiments were of sufficient value to warrant publication.

Previous experiments had shown that for the measurement of very low pressures the whole gauge must be so constructed that it could be placed in an oven and heated to a temperature of about 200° C. while on the pump. It was further desired to make the volume of the gauge as small as possible and to eliminate all metal which was not absolutely necessary. The gauge, described by Angerer, could not be heated without danger of cracking, a difficulty which has been overcome in the gauge to be described below.

Description of Apparatus.

Several different gauges were constructed varying in sensitivity so as to be used at different pressures. A typical gauge is shown in Figs. 1 and 2 and the electrical circuits are given in Fig. 3. The glass rods *GG* served as supports for the metallic parts of the gauge. All the internal electrical connections and adjustments, with the exception of the final leveling, were made before the outer glass wall *OO* was sealed on at *SS*.

[1] M. Knudsen, Ann. d. Phys., 32, p. 809, 1910.

[2] E. v. Angerer, Ann. d. Phys., 41, p. 10, 1913.

The suspension W was a phosphor-bronze ribbon 50 mm. in length which had been obtained from W. G. Pye & Co. and was listed by them as No. 0000. The movable vane VV consisted of a rectangular frame of aluminum 0.076 mm. in thickness, the dimensions of the outer rectangle being 30 × 36 mm. and of the inner 26 × 30 mm. The heating plates PP were platinum strips 4 mm. wide, 40 mm. long and 0.025 mm. thick. The deflections of the movable vane were obtained in the usual way by the reflection of a beam of light from the mirror M. Fig. 2 is a cross-sectional view through the middle of Fig. 1.

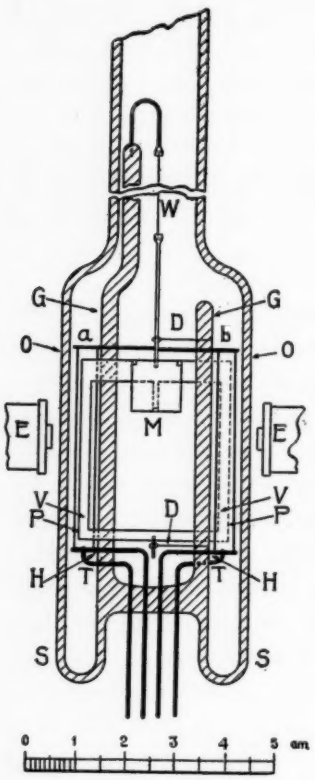

Fig. 1.

All of the platinum connections were made by electric welding, as that was found much more satisfactory than the use of any kind of solder, especially when heated. After a little practice, it was possible to weld the thin platinum heating vanes to the heavy platinum wire so as to make a perfectly continuous contact throughout its width. The phosphor-bronze suspension was connected at both ends by threading through three small holes drilled into the flattened extremities of the platinum and aluminum wires respectively. The small loops DD were so placed that they supported the movable vane V except when the gauge was leveled for taking readings. This made the gauge readily portable and, by placing in the inverted position when connected to the molecular pump, the danger of the breaking of the suspension by vibration was eliminated. One gauge of medium sensitivity was constructed so as to be sufficiently steady to be used when connected directly to the molecular pump. Large glass tubing was employed in all the connecting portions of the apparatus.

The movable vane used by Angerer consisted of silvered mica, but the present investigation has shown that such a vane is very susceptible to variations in the light falling upon it. An ordinary forty-watt tungsten lamp placed 50 cm. away so as to shine on the vane would cause a deflection of 100 mm. when the pressure was about 10^{-5} mm. of Hg. This phenomenon was shown not to be a direct heat effect by the fact that a

non-luminous Bunsen flame had no effect when brought quite close to the apparatus and that with a luminous flame the effect was immediately observed. When the silvered-mica was replaced by aluminum, the effect of light variations was small enough to be neglected. The moving system was electrically connected through the suspension to that terminal of the heating strips which was grounded, the whole being screened from external electrical disturbances by an earthed silver coating on the outside of the glass walls. In an earlier experiment, the silvering was on the inside of the walls, but this was unsatisfactory as it was impossible to free the coating from gases while connected to the molecular pump. However the above method of electrical screening was sufficiently good so long as there was no source of ionization within the apparatus; but if the gauge was connected to an ionization chamber, the electrical disturbances became very troublesome when the ionization was large. No attempt was made in this case to prevent the diffusion of the ions, although this could be easily accomplished by a suitable wire gauge.

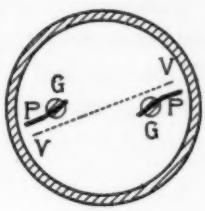

Fig. 2.

A small electromagnet, shown at *E* in Fig. 1, was employed in bringing the moving vane to rest. This was found to be quite necessary in working with the most sensitive gauges, since in a very good vacuum the damping is so small that the vane will not settle down sufficiently for the taking of readings for some time after an accidental disturbance has set it vibrating. It should be noted that the electromagnet must have either an air core or one of good, soft Norway iron, for otherwise the residual magnetism will produce a false zero if the aluminum vane is at all magnetic, as was the case with the samples of metal investigated in this laboratory. Under these conditions it is obvious that the electromagnet should be used only for damping and that the exciting current should be shut off while making observations.

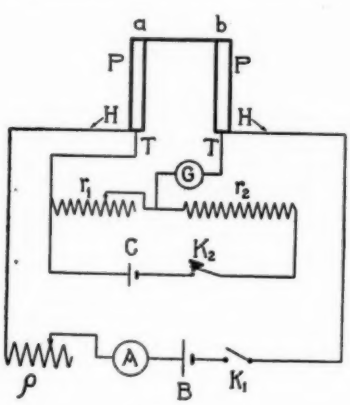

Fig. 3.

Several methods were tried for determining the temperature of the heating strips and that shown in diagram in Fig. 3 was finally settled upon as giving the most satisfactory results. The potentiometer leads *TT* were connected by electric welding to the very extremities of the platinum heating vanes *PP*. The heating current was regulated by the

variable resistance ρ and its value was read on the ammeter A. The resistance r_2 was kept constant at 10,000 ohms and r_1 varied to obtain a balance of the sensitive galvanometer G. The potentiometer battery C consisted of a carefully calibrated Weston Standard Cell. This arrangement gave an accurate method of measuring the resistance of the platinum strips PP, plus the heavy platinum wire ab, the total cold resistance being 0.17 ohm. This cold resistance was determined by plotting the curve connecting resistance and heating current under a constant low pressure and extrapolating backward to the intersection with the axis of resistance. If the resistance is measured for small currents, the value at zero current, that is the cold resistance, can be determined very accurately. A typical curve is shown in Fig. 4. The temperature coefficient of resistance

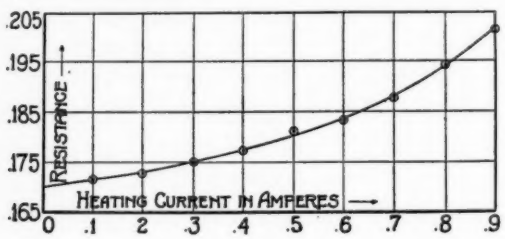

Fig. 4.

of the platinum, which contained a small amount of iridium, was carefully determined and was found to give a linear relation within the range of temperatures employed. The value of the coefficient was 2.35×10^{-3} ohms per degree Centigrade. With this system one can determine the mean temperature of the heating strips with sufficient accuracy, the error for temperature differences of about 50° C. being less than four per cent. It should be mentioned that numerous attempts were made to employ fine thermo-couples, but it was practically impossible to make a good thermal contact with the heaters such that it would remain constant upon heating to 200° C.

CALCULATION OF THE CONSTANTS OF THE GAUGE.

According to the theory given by Knudsen, the gas pressure within the gauge is given by the formula

$$P = \frac{2K}{\sqrt{T_1/T_2} - 1},$$

where K is the uniform pressure in dynes on each cm.^{2} of the movable vane and T_1 and T_2 are the absolute temperatures of the heating strips and of the moving vane respectively. If the difference in temperature is

small as compared to the absolute temperature, the formula may be written

$$P = 4K \frac{T_2}{T_1 - T_2}.$$

It is to be noted that this formula is independent of the nature of the gas or vapor to be measured. The constant K was found in terms of deflection, the constants of the suspension being determined in the usual way from the period of the moving system and the calculated moment of inertia of the suspended rectangular frame. For the gauge whose dimensions are given above, the period of a complete oscillation was 10.0 sec. and the calculated moment of inertia of the moving vane was 0.074 gm. cm.^{2} This gives for the pressure

$$P = 2.9 \times 10^{-5} \frac{T_2}{T_1 - T_2} d \text{ dynes},$$

or

$$P = 2.2 \times 10^{-8} \frac{T_2}{T_1 - T_2} d \text{ mm. of Hg.},$$

where d is the deflection in mm. on a scale at a distance of one meter from the mirror. As it is easily possible to obtain a temperature difference of 100° C. and since a deflection of 0.5 mm. can be observed, the gauge will measure a pressure as low as 3×10^{-8} mm. of Hg.

It was thought that at these very low gas pressures the radiation pressure might have an appreciable effect as compared to that of the molecular bombardment. To test for such an effect, the deflection was obtained for several different values of the temperature of the hot platinum strips, when a very constant pressure had been obtained. If the radiation pressure is small enough to be negligible there ought to be a linear relation between the deflection and the temperature difference, while if it is not negligible the deflection should increase more rapidly. The accompanying table shows that the radiation pressure does not have an appreciable effect at a gas pressure of about 10^{-6} mm. of Hg. for temperature differences up to 85° C.

TABLE I.

Temp. Diff. in °C.	Deflection in Mm.	Calculated Pressure $\times 10^{-6}$ Mm. Hg.
8	4	3.4
20	9	3.1
35	17	3.3
65	28	2.7
83	40	3.2

MEASUREMENTS OF LOW PRESSURE.

The lowest pressure obtained with a Gaede molecular pump was measured by a specially constructed gauge, the pressure being 3×10^{-5} mm. of Hg. A Gaede rotary-box pump was used as a fore-pump giving a pressure of 0.01 mm. of Hg., and the molecular pump was run at 8,000 R.P.M. The above vacuum was obtained after pumping for about 3 hours and with the gauge connected as closely as possible to the molecular pump, the total volume consisting only of the gauge and connecting glass-tubing. However in this case the glass walls of the gauge were not heated.

It is interesting to compare the vacuum given by the molecular pump with that obtained when a side tube containing cocoanut charcoal is immersed in liquid air. By the latter method the pressure was reduced after about 36 hours to 2×10^{-7} mm. of Hg. If the liquid air were removed, the pressure would increase to a value somewhat higher than that measured when the gauge was sealed off the molecular pump, but it would then decrease again, slowly approaching the value obtained at sealing off. On the other hand if the liquid air is replaced before this gradual decrease begins the vacuum very quickly reaches the value previously obtained after about 36 hours. This effect is probably due to absorption on the walls of the glass and on the metallic parts of the apparatus which makes the original action of the charcoal and liquid air so slow. If the walls are carefully heated while the gauge is connected to the molecular pump, this phenomenon is not so pronounced.

The lowest pressure which we have measured was obtained by the use of charcoal and liquid air in the usual way supplemented by the evacuating action of a tungsten filament sealed into a side tube and kept running for 130 hours. The pressure had reached the value 5×10^{-8} mm. of Hg. when the investigation was stopped by an accident to the apparatus.

Some interesting data was obtained on the efficacy of rubber valve-grease for holding a good vacuum. A system, which contained three large stopcocks and a large ground-glass joint, attained a vacuum of 10^{-6} mm. of Hg. under the action of charcoal and liquid air. The vacuum remained constant at this value for several days while the charcoal was kept immersed in the liquid air. However when the charcoal tube was disconnected by closing one of the stopcocks, the pressure gradually increased but at a very slow rate.

As the Knudsen absolute manometer measures the pressure independently of the nature of the gas, it affords a convenient method of determining the rate at which charcoal immersed in liquid air will remove

different gases. This effect was investigated with oxygen, nitrogen and hydrogen, but it was impossible to get an accurate quantitative comparison as the oxygen was removed too quickly under the action of the liquid air. However some idea of the relative rates may be obtained from the data in Table II. In each case the pressure before inserting the known gas was reduced to the same value, viz. 1.5×10^{-6} mm. of Hg., the charcoal being thoroughly heated while connected to the molecular pump. Hydrogen was investigated first, then oxygen and nitrogen in the order named. The values given in the first column are the times after

TABLE II.

Time of Action.	Pressure in Mm. of Hg. for		
	Hydrogen.	Oxygen.	Nitrogen.
Zero	485×10^{-6}	500×10^{-6}	450×10^{-6}
5 seconds	———	290×10^{-6}	———
10 seconds	———	170×10^{-6}	———
1 minute	460×10^{-6}	2×10^{-6}	15×10^{-6}
5 minutes	410×10^{-6}	1.5×10^{-6}	———
20 minutes	290×10^{-6}	———	———
1 hour	190×10^{-6}	———	5×10^{-6}
3 hours	135×10^{-6}	1.5×10^{-6}	———
10 hours	135×10^{-6}	1.5×10^{-6}	5×10^{-6}

the charcoal tube has been connected to the gauge by opening the stopcock. For the oxygen, the measurements were taken by leaving the stopcock open only for a few seconds at a time. No special care was taken in the preparation of these gases and consequently they were not very free from other gases and vapors but were sufficiently pure to clearly show the phenomenon.

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A COMPARISON OF THE LONGITUDINAL AND TRANSVERSE JOULE MAGNETOSTRICTIVE EFFECTS IN THE SAME SPECIMENS OF STEEL AND NICKEL.

BY S. R. WILLIAMS.

THE interesting discovery made by Joule[1] that a rod of iron would change its length when subjected to a longitudinal magnetic field led to his investigation of the effect of a transverse field upon the length of a piece of iron. In order to get a transverse field imposed upon an elongated specimen of iron, Joule sent an electric current through an insulated wire inside of an iron pipe. The circular magnetic field about the wire in the pipe produced a field normal to the length of the pipe whose change in longitudinal dimension was to be measured. The primary object of this latter investigation by Joule was to discover whether or no volume changes occurred when the iron was magnetized. Joule had no facilities for obtaining high field strengths, hence his results show that in the longitudinal effect only an elongation occurred and in the transverse only a shortening. From this relation he concluded that there was no change in volume.

It is to Bidwell[2] that we owe the extension of our knowledge of the effect of strong longitudinal magnetic fields on iron rods, viz., an elongation for weak fields and a contraction for strong in which for the latter there were certain field strengths which made the specimen shorter than in its virgin state. The question therefore arises as to whether the transverse field produces opposite effects to those of the longitudinal for all field strengths, *i. e.*, will the transverse effect be an elongation, for strong fields in the case of iron?

In 1894, Bidwell[3] contributed two short articles bearing upon the longitudinal and transverse effects which occur in iron rings when they are magnetized. Since the appearance of the papers by Joule and Bidwell, little or no additional work has been done on this subject. Because this subject has an important bearing upon a working hypothesis of magnetization which the author has used with considerable success in

[1] Joule, Phil. Mag., p. 76, Vol. 30, 1847.

[2] Bidwell, Proc. Roy. Soc., 1885–1890. See Trans. Roy. Soc. also.

[3] Bidwell, Proc. Roy. Soc., 1894.

other magnetic phenomena, it seemed desirable to compare these two effects of magnetization in the same specimens of ferro-magnetic substances. The hypothesis, on which the writer has been working, indicates that qualitatively there should be this reversal for all field strengths in all ferro-magnetic substances, and since the work of Bidwell did not attempt specifically to compare these two effects, but to determine volume changes due to magnetization, it seemed not out of place to present some results which have been obtained upon this subject. Bidwell used toroids in the investigation of the changes in length due to longitudinal and transverse fields. One advantage of the toroid is that, since there are no free poles developed, there is no demagnetizing field, and hence the magnetizing force is the same as the magnetic field which would exist inside of the magnetizing coil without an iron core. There is, however, a practical objection to this form in that every sample of ferro-magnetic substance to be tested requires winding with a magnetizing coil and since this must be done by hand the process is one which consumes a great deal of time. Bidwell's work is limited to two specimens of iron, one in the annealed and the other in the unannealed state. So far as the author knows this has been the extent of comparative work done on these two effects.

In the experiments described below, measurements of changes in dimensions were made upon two specimens of steel and two of nickel, the transverse effect in nickel being measured with considerable difficulty. I wish here to express my thanks to Mr. Paul Weeks, one of our advanced students, for the help and skill in carrying out the measurements.

METHODS.

There seem to be two ways of comparing these two magnetostrictive effects. Let A, B, C, D, Fig. 1, represent the cross-section of a cube of steel to which has been applied a magnetic field, H, in the direction indicated. Obviously if the change in length of AC is measured as the field, H, is varied, we have the ordinary longitudinal Joule effect, whereas if DB or the length normal to the page is measured we have the transverse Joule effect. This is the method which Bidwell used in measuring the two effects, *i. e.*, keeping the direction of the magnetic field fixed he measured the variations of two dimensions at right angles to each other, one of which was parallel to the field applied.

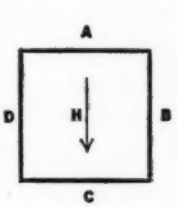


Fig. 1.

The other method is to apply the field, H, as indicated and measure changes in AC, then apply the field parallel to DB and again measure AC.

In this case the dimension whose change in length was measured has been the same and the field has been applied in two directions at right angles to each other, one of which was parallel to the dimension whose variation was measured.

Both methods are open to question, but the latter seemed to have fewer objections than the first, particularly for specimens whose ratio of length to diameter was several hundred. If the first method is pursued the aeolotropic condition of the material will certainly produce a coefficient of change of length different in one direction from that in the other, consequently the comparison of the two changes cannot be made quantitatively. On the other hand when the field is applied in two different directions the aeolotropic nature of rolled and drawn metals prevents the securing of similar fields, as we should have for quantitative comparative tests. The latter method is most readily applied to specimens in long rod or tube form. It seemed, therefore, that conditions most nearly alike in these two effects could be secured when the direction of the field was varied and the direction of the dimension to be measured was kept the same. In other words no absolute comparative tests can be made of these two magnetostrictive effects unless one has a perfectly homogeneous specimen with which to work. So far as the author knows no such samples are obtainable. The author has started work to see what can be done in cast specimens. This study is therefore concerned with a qualitative comparison of the two magnetostrictive effects in the same specimen.

The first specimen of steel was a piece of water pipe, 30.74 cm. long, and whose inner and outer diameters were 10.20 and 11.35 cm. respectively. The wire was wound about it in the form of a toroid, Fig. 2, but not placed directly in contact with the steel so as to restrict the expansion of the cylinder. This was accomplished by winding the insulated wire about a wooden framework which consisted essentially of two wooden rings, R, R, held apart by small brass rods not shown in the figure. The windings were of No. 13, double cotton covered, copper wire, B. & S. gauge, making three hundred turns in all. The value of the circular field was calculated from the equation,

$$H_c = \frac{2nI}{10r},$$

where n indicates the number of turns, I the current in amperes, and r equals 10.77 cm., the mean radius of the iron cylinder.

The change in length of the cylinder was measured by means of the displacement of interference bands produced by the light reflected from

the two glass surfaces, g, g, shown in Fig. 2. Light from a sodium flame, S, was reflected by the mirror, M, down to the optical surfaces of g, g and thence reflected back by nearly the same path to an observing micrometer microscope. This optical device for measuring the change in length could be used without disturbing the system both in the longitudinal and transverse effects. The method of observing the displace-

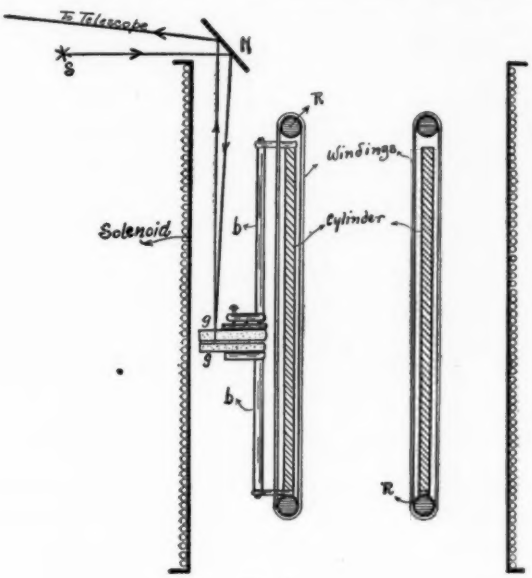


Fig. 2.

ment of the bands was to locate the position of one band with a fixed cross-wire in the micrometer eye-piece and then set the movable cross-wire about where the band would come when the field was applied. After a trial or two the distance between the movable and fixed cross-wires would represent with considerable accuracy the displacement of the band. Knowing the width of the band it was possible to determine the amount of the change in length of the steel cylinder. This method of measuring the shift did not require the magnetizing current to be left on for any length of time and consequently heat effects were minimized.

The change in length was measured as the field was increased from zero upward, with several makes and breaks of the circuit for each field strength measured. Successive sets of readings were taken in this way and the mean results are plotted in Curve 2, Fig. 3. Demagnetization by reversals occurred after each series of readings.

The longitudinal effect was obtained by placing a solenoid of a large cross-section around the toroid as shown in Fig. 2. The axis of the

toroid coincided with that of the solenoid. The ends of the cylinder were 11.5 cm. back from the ends of the solenoid. The current both for the toroid and the solenoid was supplied by a storage battery. The measurement of the change in length due to the longitudinal field was

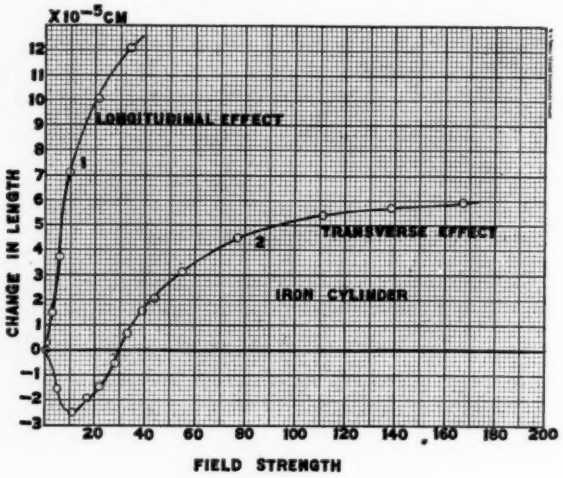


Fig. 3.

carried out in exactly the same way as for the transverse field. The results are shown in Curve 1, Fig. 3, after making corrections for the end effects of the solenoid and the demagnetizing effect of the cylinder itself.

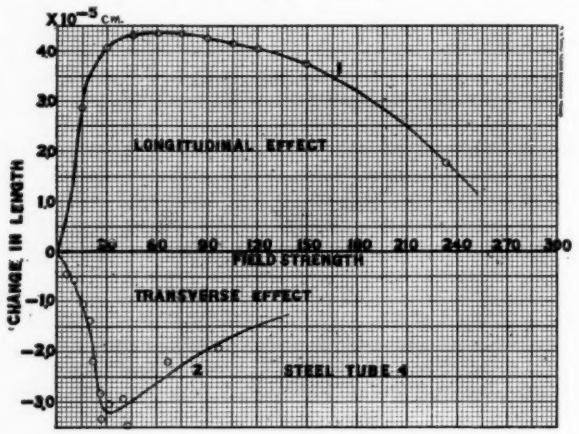


Fig. 4.

The solenoid had a length of 53.7 cm. and an average diameter of 28.74 cm. There were six layers with a total number of 1,466 turns.

The next specimen tested was a steel tube 80 cm. long and 0.297 cm.

in mean radius. This is known as tube 4 in previous investigations.[1] The device for measuring the changes in length due to the longitudinal and transverse fields was the same as used in former work. The transverse field was obtained by passing a current through only a few turns of insulated wire inside of the tube and consequently not very large fields could be obtained. The results are shown in Curves 1 and 2, Fig. 4.

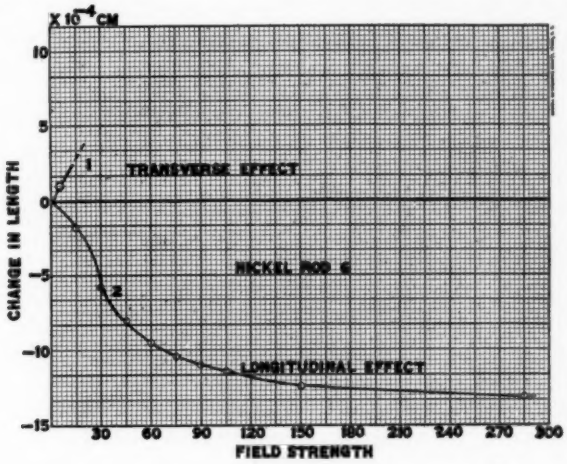


Fig. 5.

For the two specimens of nickel which were tried, much more difficulty was encountered in measuring the change in length for the transverse field than was experienced with the steel samples. This was due to the sensitiveness of nickel for heat effects. Curves are shown for only one specimen as the two were similar. For the few field strengths which could be measured only an increase in length was found which is the reverse of that for the longitudinal field (Fig. 5).

Discussion of Results.

Roughly, the curves seem to indicate this reversal of effect when the longitudinal and transverse fields are applied. The results obtained from the long specimen (80 cm.) seem the most trustworthy. The large demagnetizing factor for the short steel tube decreased the effective value of H, the field of the solenoid, to so large an extent that large field values could not be obtained for comparison. The values for the demagnetizing factors used were obtained from equations given by Ewing[2] and applied to a hollow cylinder, just as one would to a solid cylinder. This was done because Grotrian[3] has shown that for fields which do not attain

[1] Phys. Rev., p. 261, Fig. 7, Vol. 34, 1912.

[2] Ewing, Magn. Induc. 3d ed., p. 25.

[3] Grotrian, Annal. der Physik, Vol. 52, p. 735, Vol. 54, p. 452.

values giving a saturated condition the demagnetizing factors of solid and hollow cylinders are practically the same. As to the reversal of effects, suppose one had a homogeneous specimen of a ferro-magnetic substance and assumed that the turning of the elementary magnets was the cause of the changes in length; then if the elementary magnet had the form of an oblate spheroid it would be easy to see why the application of a transverse field produced the reversed effect to that brought about by the longitudinal field. I have indicated this possibility in a former paper.[1] If the curves shown there for the single elementary magnet held for the group, then qualitatively the longitudinal and transverse effects should be the reverse of each other; but as pointed out, the aeolotropic condition of the specimen precludes any exact relation occurring in ferro-magnetic substances in drawn and rolled samples.

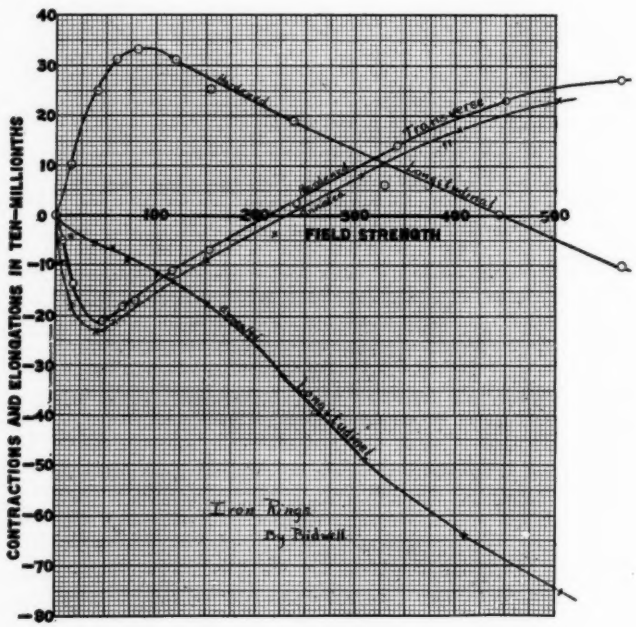


Fig. 6.

Bidwell[2] states that he had a specimen of iron which showed a contraction for all field strengths, and cites it as the only specimen which has yet been found showing this phenomenon. The author has found a specimen of steel which to all appearances showed the same phenomenon. Not until a much larger multiplying power of the device for indicating the change in length was used did it show a very small

[1] PHYS. REV., p. 40, Vol. 34, 1912.

[2] Bidwell, Proc. Roy. Soc., Vol. 56, 1894.

increase in length for weak fields. If this was the case with Bidwell's specimen then his work would be still more confirmatory of the reversibility of the two effects. His results are shown graphically in Fig. 6. Bidwell's specimens were very small while the rods and tubes used in my work were 80 cm. long and consequently gave an advantage for multiplying the effect.

As one studies the various theories of magnetism he is impressed with how little they have to say regarding magnetostrictive effects and yet if one should classify the various magnetic phenomena, the various magnetostrictive effects would make the major part of the phenomena. One is reminded of the words of Joule,[1] that "when we are able to answer some of the questions regarding magnetostrictive effects in a satisfactory manner we shall probably have a much more complete acquaintance with the real nature of magnetism than we at present possess."

SUMMARY.

1. The results show a qualitative reversal of the two effects as the planetesimal hypothesis would indicate.

2. An exact quantitative reversal is not to be expected for several reasons: (*a*) non-homogeneity of the specimens, (*b*) in the transverse field there is not a uniform magnetic field applied, varying inversely as the distance out from the center of the specimen when the specimen is a hollow cylinder and the current is conducted through an insulated wire inside of the cylinder. In case the specimen is a solid cylinder then the field varies inversely as the square[2] of the distance from the center because the current flows in the specimen itself as a conductor, (*c*) the elementary magnets affected by the longitudinal field will be different from those influenced by the transverse field.

3. This comparison of the two Joule magnetostrictive effects should, according to previous investigators, give some clue as to change of volume. Knott[3] was undoubtedly the first to show that magnetization is generally attended by considerable change in volume, but later investigators did not find a relation existing between different specimens for volume changes which they had found for changes in length. For instance, since iron elongates and nickel contracts for initial field strengths, one might expect a difference in behavior of volume changes. Such is not the case as pointed out by Nagaoka and Honda.[4] Both metals increase in volume by magnetization. From the standpoint of

[1] Joule, Phil. Mag., p. 76, Vol. 30, 1847.

[2] Northrop, PHYS. REV., Vol. 24, p. 479, 1907.

[3] Bidwell, Proc. Roy. Soc., vol. 56, 1894, p. 99.

[4] Nagaoka and Honda, Phil. Mag., Vol. 4, p. 71, 1902.

the planetesimal hypothesis, change in volume arises from the changed piling of the elementary magnets due to their orientation and there should be no particular relation between volume changes and the other magnetostrictive effects just as Nagaoka and Honda have shown.

4. This work points out why Berget[1] in working with a cylindrical bar measuring 5.2 cm. long and 1.95 cm. in diameter found that the length of the bar was still increasing at a field strength of 540 units. He neglected to take account of the demagnetizing factor which I have done in the case of specimen 1. The desirability of using long thin specimens in measuring the various magnetic effects is here again pointed out.

5. A complete theory of magnetism must explain the various magnetostrictive effects as well as the other magnetic phenomena.

PHYSICAL LABORATORY,
OBERLIN COLLEGE, OBERLIN, OHIO,
June, 1914.

[1] Berget, Comp. Rend., p. 722, Nov. 7, 1892.

WAVE-LENGTH-SENSIBILITY CURVES OF CERTAIN CRYSTALS OF METALLIC SELENIUM; AND A PARTIAL EXPLANATION OF THE COMPLEXITY OF LIGHT-ACTION IN SELENIUM CELLS.

BY L. P. SIEG AND F. C. BROWN.

IN a recent paper[1] it was shown that there was no apparent characteristic wave-length-sensibility curve for light-sensitive selenium, except when that selenium was made light-sensitive under very definite physical conditions. Some of these conditions have recently been worked out and published by Dieterich[2]. The conclusion seemed advisable if not necessary that the selenium in the selenium cell must be made up of a varying crystal structure, and that in some way the varying characteristics could be explained in terms of the individual crystal units composing the selenium. The recent production by one of us of several crystals of large size[3] has made it possible to obtain further evidence as to the manner in which the individual crystals might explain the variations in mass selenium. In the present work we have studied the wave-length-sensibility curves of a number of crystal forms and have already obtained curves which can explain most of the variations found in selenium. As predicted in our former paper we have found these crystals to have directive axes in the property of light-action as well as in the property of light transmission and crystal structure.

The method for obtaining the wave-length-sensibility curves was in the main the same as that described in our former papers. However for adjusting to equal energy throughout the spectrum the procedure was altered to permit of more rapid working. An aluminium sector disc was calibrated in use with a given Nernst glower, in such a manner that a particular setting of the sector for a corresponding wave-length always allowed the same energy to fall on the thermopile or the crystal as desired. For comparative work with different crystals this method was very satisfactory indeed. From time to time the energy values were checked just prior to each light exposure on the crystal, and as these results

[1] PHYS. REV., N.S., Vol. 4, p. 48, 1914.
[2] PHYS. REV., N.S., Vol. 4, p. 467, 1914.
[3] PHYS. REV., N.S., Vol. 4, p. 85, 1914.

checked and because crystals of like character always gave the same sensibility curves under the same conditions, it was certain that no important errors accrued from the method used.

Some of the crystals were not sensitive enough to be used with short periods of illumination. For this reason all crystals were compared for illumination of 30 seconds' duration. Just what differences exist because of varying periods should be investigated in connection with the rates of change as designated in previous papers.

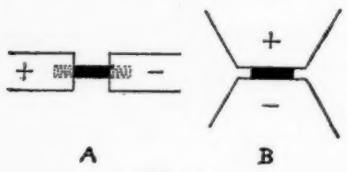


Fig. 1.

The light-sensibility of the crystal was obtained when it was placed between electrodes of the same material as diagrammed in Fig. 1. Both silver and brass electrodes were used at different times, but thus far there does not appear to be any importance to be attached to the material or the structure of the electrodes. In one apparatus, designated *A*, the crystal was pressed against a glass plate by two silver electrodes acting on the ends of the crystal. The illumination could thus be applied to either the front or the back side of crystal, as well as to the edges of the crystal. In the apparatus, *B*, the entire crystal was clamped between brass electrodes. It is to be noted that in the apparatus *A* the light acts directly on the part of the selenium that is not under pressure by the electrodes and that conversely the crystal when placed in apparatus *B* was under pressure at the place of illumination. Further on will be mentioned slight modifications of these methods of clamping. It will appear that the advantages of any one method will depend largely on the shape of the crystal to be used and the crystal face to be illuminated.

Comparative Results with Individual Crystals and with Selenium Cells.

At different times we have shown that light-sensitive selenium is not a simple substance but a complex mechanism and we have taken the view that the complexities arise from more or less elementary constituents. This requires that the atom of selenium can not be the sole unit in the mechanism acted upon. The information that we have thus far is very strong evidence that the variation of the properties of light-sensitive selenium is inherent in the crystals that compose it, that these crystals by virtue of their form, position and location determine the properties of the selenium mass. The reader will we believe become at once sympathetic to this view by a casual observance of the wave-length-sensibility curves in Figs. *2a* and *2b*. Fig. *2a* is taken from our former

paper[1] and represents the characteristic curves of various varieties of light-sensitive selenium as found in selenium cells. Fig. 2*b* represents the characteristic sensibility curves of individual crystals, which differ in crystal form or differ as to the direction of the crystallographic axis with regard to the direction of illumination. We do not claim to have exhausted the list of crystals or possible curves that might be obtained

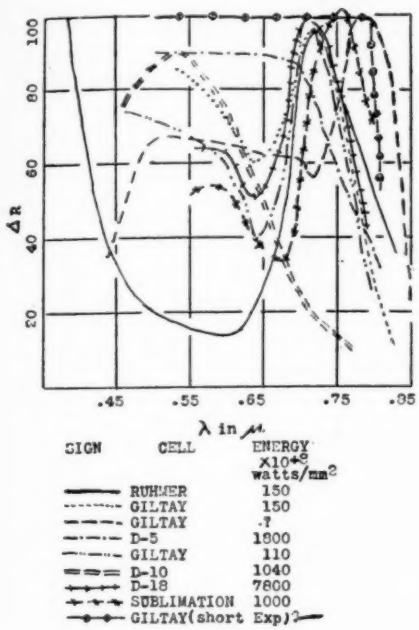


Fig. 2*a*.

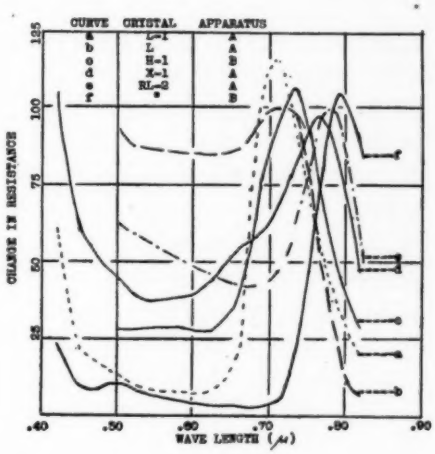


Fig. 2*b*.

with individual crystals. In fact some crystals already discovered have not been investigated because of their insufficiently large size. However the resemblance between the two sets is striking indeed. Both show some curves with a maximum in the ultra-violet, and both show the same range of the maximum in the extreme red. The only lack of agreement is in the fact that we have not yet discovered that crystal which has a distinct maximum in the region of .55 μ, such as found in the typical Dieterich cell. And along with this fact it must be noted that we have examined no crystal which in any position showed a diminishing sensibility at the blue end of the spectrum. In making these comparisons we have made no allowance for the enormous difference in the reflecting power of the selenium in selenium cell from that of the crystal. The former absorbs about 98 per cent. of the light in all parts of the spectrum, while the

[1] Loc. cit.

latter probably does not absorb more than 60 to 70 per cent. of the incident light. What may be the consequences of this difference is not certain. It will of course be advisable to measure the absorption constant of the crystals.[1] In as much as the selenium in mass does not show a very great selective absorption and since the shifting of the red maximum is almost identical with the selenium crystals and the selenium mass, it is not expected that the crystals will show much of a variation in reflecting power in this region.

In what ways the crystals give rise to varying sensibility curves will be taken up in the remainder of the paper.

EACH CRYSTALLINE FORM HAS A DISTINCTIVE CHARACTERISTIC CURVE.

Before asserting that each crystalline form of selenium has characteristic photo-electrical properties, it is advisable to know that the character of the curve is not altered by other physical conditions which might vary in the experiments. For example it was determined that the direction of current flow did not alter the sensibility curves when the illumination was on the same part of the crystal. Since it had been shown by one of us[2] that the resistance might vary by a factor of several hundred depending on the pressure on the crystal, there was considerable doubt as to whether the pressure might control the character of the sensibility curves. In fact we mentioned in one of our former papers that a part of the variations in the selenium cells might be accounted for by variations in the pressure on the selenium as it was placed on the cell form. We therefore placed an acicular hexagonal crystal between the electrodes of apparatus *B* and mapped out the sensibility curves when the pressures were of such a magnitude that the conductivity increased by a factor of 50 to 1. The intensity of illumination and other physical conditions were unchanged. The results of the investigation are shown by the two upper curves in Fig. 3. There is no evidence of any change in the position of the maximum or in the ratio of the values of the maximum to the minimum as a result of the change in pressure.

Since Pfund and ourselves had observed an ironing out of the maximum in certain selenium cells by diminished illumination it was thought advisable to see if the sensibility curves underwent any change when the intensity of illumination was varied. We used the same crystal and apparatus just mentioned above. These comparison curves are also

[1] Recently a preliminary test was made to determine the reflecting power of these crystals throughout the spectrum. This was found to be practically constant, and probably between 30 and 40 per cent, thus agreeing with the values of Foersterling and Freédericksz (Amer. d. Phys. 43, 1227, 1914) for metallic and amorphous selenium mirrors.

[2] PHYS. REV., N.S., Vol. 4, p. 93; 1914.

shown in Fig. 3. Again there is no apparent change in the curves due to varying intensity. This result is particularly important at this point because it has not been determined if there is a variation of the reflection coefficient in different crystals or along different axes of the same crystal. If there is such a selective variation we have no means of knowing just what is the relative amounts of energy absorbed when we can measure only the incident energy. Unless the selective variation is of some magnitude, we can be reasonably certain that the amount of light absorbed by the crystal does not concern the character of the sensibility curve. Of course electrical theory requires that the reflection constant should vary with the conductivity of the material. But since the resistance of these crystals is so large, it is believed that the reflection due to the free or conducting electrons is small compared to the reflection by the charges in the bound atomic structure. The values of the intensity in Fig. 3 are for the incident energy. The values of the absorbed energy must be many times smaller, but even if the absorbed energy does vary by a factor of fifty the ratios of the absorbed energy surely can not be enough different to make any material error in the conclusions that we have drawn, concerning the independence of light-action and the pressure effect.

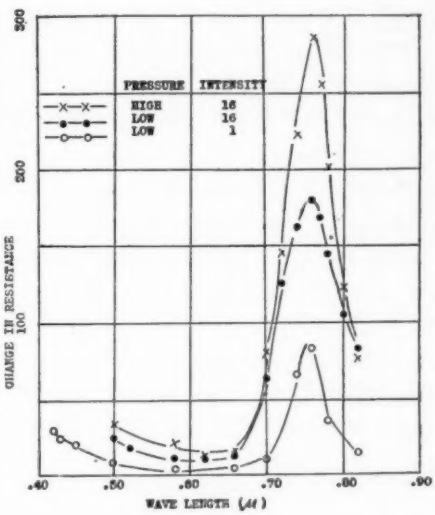


Fig. 3.

It has been shown[1] for selenium cells and also for single crystals that the resistance varies greatly with the electromotive force across the selenium. It is sufficient to mention here that we could not observe any change in the sensibility-curves due to a variation of the resistance by use of varying potential differences between the electrodes.

In the formation of the crystals there were sometimes variations of 20° or 30° in the oven temperature. As nearly as could be discerned such temperature treatment did not alter the sensibility curve of a given crystal form.

Having shown that the preceding conditions did not alter the character

[1] Paper by Brown and Stebbins, PHYS. REV., 26, p. 273, 1908 and Brown, PHYS. REV., 33, p. 1, 1911, and other paper not yet published.

of the sensibility curves, we proceeded to investigate the variation of the sensibility curves for the different crystal forms. For this we selected three specimens which were of sufficient size for the purpose. One (*L*–1) was a lamellar crystal[1] with axes perpendicular to the edges. Its size was about $4 \times 2 \times .2$ mm. A second was of the acicular hexagonal form (*H*–2), of size about $10 \times .4 \times .4$ mm., and the third was a combination of crystals that had grown out from a central hexagonal spine. The angles and the form of this are not yet known, but the crystal is probably of the second crystal system. Crystals of the above types are shown in the above articles referred to.

The lamellar crystals were placed in apparatus *A* and illuminated perpendicular to either of the large flat surfaces. In either case the sensibility was that shown by the upper curve in Fig. 4.

The acicular crystals were placed in apparatus *B*. They were illuminated perpendicular to the axis of the crystal. It was apparently immaterial as to which of the six faces were illuminated. The curve for this type showed a sharp maximum in the same place as that for the lamellar crystal (see *H*–2, Fig. 4), but it was very much sharper and its magnitude was relatively much greater than for the lamellar crystal.

The third crystal showed a maximum at wave-length .7 μ, but it was not as sharp as that of the acicular crystal (see *X*–1, Fig. 4). It should be mentioned that all the curves in this paper are drawn each to an arbitrary scale, so that the relative sensibility of each crystal can not be ascertained from the curves. In the crystals just referred to however the sensibility was of the same order of magnitude in each.

The Same Crystal Gives Different Curves When Illuminated Along Different Axes.

Previously we have shown the crystals to be doubly refracting.[2] Electrical theory requires that any material having directive axes in its optical properties in this way, shall also show directive properties in any phenomena involving electro-optical interactions. Simply stated if a crystal shows electrical phenomena as a result of light acting upon the crystal as a crystal and not as an element, the electrical phenomena should vary when the illumination is along different axes. On the other hand if the light action should be on the atoms without regard to the crystal mechanism it is not conceivable how there could be any difference in the sensibility curves arising from illuminating different sides of the crystal providing the reflecting power is constant.

[1] For further information about these crystals see papers by Brown, PHYS. REV., loc. cit., and by Brown and Sieg, Phil. Mag. (6), Vol. 28, p. 497. 1914.

[2] Brown, loc. cit.

Several crystals were investigated as to the conductivity change when illuminated along different axes. The best specimen was a lamellar crystal $4 \times 2 \times 0.2$ mm. The large surfaces were rectangular and approximately parallel. We were not able to determine the angles of the edge faces.

When the illumination was directed on either of the large faces as shown by the arrow, marked 1 (Fig. 5), the sensibility began to increase rapidly at wave-length .66 μ and held a broad maximum with the mean

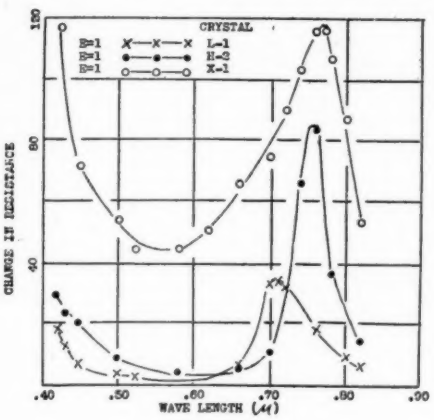


Fig. 4.

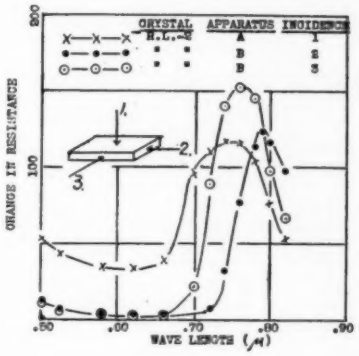


Fig. 5.

position at .74 μ. At $\lambda = .80\,\mu$ there was a very large sensibility. By illuminating either of the short edges of the crystal the sensibility had just started to rise at $\lambda = .74\,\mu$, the position where with side illumination the maximum occurred. In this instance the maximum was very sharp and located at .79 μ. In the infra red beyond wave-length .82 μ this edge of the crystal was more sensitive relatively to the minimum than was the flat surface at its maximum. When either of the longer edges was illuminated as shown by arrow 3, the maximum was at .76 μ. Thus a single crystal may have its maximum shifted at least five wave-lengths by changing the side of the crystal that is illuminated. We carefully observed that the direction of current flow made no difference in these experiments.

It is altogether improbable that the variation of the selective absorption plays an important rôle in giving these different sensibility curves. If so the results are consitent with the idea that the light acts upon the crystal structure rather than upon the atoms. However this mode of explanation of the shifting of the maximum can be sidestepped perhaps if we wish, by attributing the shift toward the longer wave-lengths to transmitted action as will be explained in the last section of this paper.

THE ACTION OF POLARIZED LIGHT.

We have made some observations on the action of polarized light, the significance of which is satisfying only in a general way. The experiments were called forth after we had investigated the effect of varying the angle of incidence on a lamellar crystal. By such variations of the angle of incidence, sensibility curves were obtained for different angles as indicated in Fig. 6. For an angle of about 60° there was a decided change in the character of the curve but for angles larger or smaller the curve form was almost unchanged. It was thought that this might be about the angle of maximum polarization, and that consequently only one component of the light might enter the crystal at this angle.

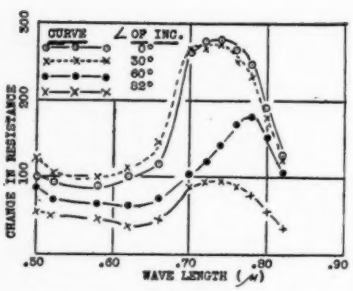


Fig. 6.

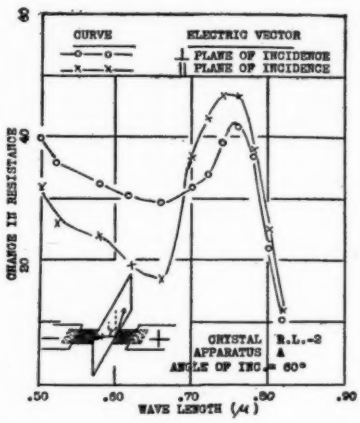


Fig. 7.

We therefore tried first light polarized in the plane of incidence and then at right angles to this plane. For all angles of incidence except 60° there was no change in the character of the sensibility curve, but at about this angle the effect of light polarized in opposite planes was quite different. When the electric vector (see Fig. 7) of the light was perpendicular to the plane of incidence the sensibility curve was much like that shown for the same angle shown in Fig. 6. But when the electric vector was parallel to the planes of incidence the maximum was relatively much broader and higher than in the previous case.

A part of the difference between the location of the maximum in Figs. 6 and 7 may have arisen from the fact that we had no accurate means of setting the angles.

We are concluding from our experiments first that our Hilger monochromator partially polarizes the light that passes through it and secondly that under certain conditions a given intensity of illumination may produce different results depending on its state of polarization.

THE DIRECT AND THE TRANSMITTED ACTION OF LIGHT.

Recently we have shown[1] that the seat of light action in selenium crystals is distributed throughout the crystal, and that light may alter the conductivity of a crystal 10 mm. or more away from the point of impingement. At that time we had not succeeded in determining whether this action could be transmitted from one crystal to another. Now we have gone further and found not only that the action of light can be transmitted from one crystal to another, but we have also mapped out the sensibility curve for such indirect action and compared it with the direct action, where the light falls on the part of the selenium between the electrodes.

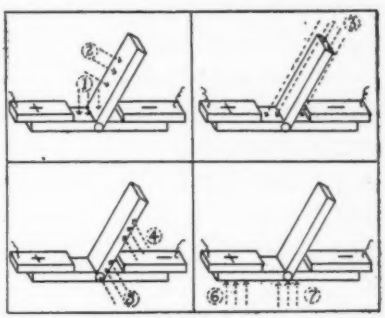


Fig. 8.

We chose for this work a lamellar crystal to the middle portion of which was grown another crystal. This crystal and the apparatus *A* are shown in a very highly conventionalized way in Fig. 8. The dotted arrows show the portions that were illuminated. Wherever any or most of the light fell upon the part of the crystal carrying the current it was called direct action as indicated by the change of conductivity of the crystal. Contrarily if the light impinged on any part of the crystal

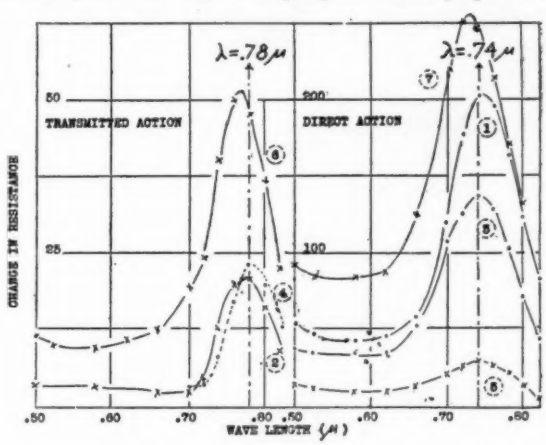


Fig. 9.

that did not carry the current, the light effect was designated as transmitted light action.

In Fig. 9 are shown the sensibility curves, on one side for the trans-

[1] Phil. Mag., Ser. 6, Vol. 28, p. 497, 1914 and PHYS. REV. N. S., Vol. 4, p. 85.

mitted action of light and on the right side for the direct action of light. It may be seen that in positions (1), (3), (5) and (7) Fig. 8 the light acts directly on the part of the selenium that directly takes part in the conductivity. The corresponding curves in Fig. 9 show the maximum in all cases to be at about .74 μ. But when the conductivity is altered by transmitted action as by the impingement of the light at positions (2), (4) and (6) the maximum is shifted to = .78 μ. Also it should be noted that in the transmitted action the ratio of the maximum to the minimum is of the order of 5 to 1 while in the direct action this ratio is only about half as great. Thus the position and the relative magnitude of the maximum depend on whether the light impinges directly on the part of the crystal that conducts or whether the change of conduction takes place at a distance from the point of impingement. Of course it is impossible to say what constitutes direct action or to separate entirely the two actions in the so-called direct action. This latter difficulty arises partly from the fact that a part of the light is always absorbed near the surface and does not penetrate all the conducting selenium even in the most favorable condition. Thus if we could obtain and isolate the direct action completely we might find the maximum at considerably shorter wave-lengths than we have indicated.

In this connection an interesting experiment that suggests itself is to see if the thickness of the selenium in the selenium cell determines the position of maximum sensibility. Thus the selenium blocks studied by White[1] should show a maximum far out in the red, because most of the change of conductivity by light in these blocks must be an indirect or transmitted action.

[1] Phil. Mag., Ser. VI, Vol. 27, p. 370, 1914.

ON THE SILVERING OF QUARTZ FIBERS BY THE CATHODE SPRAY.[1]

BY HORATIO B. WILLIAMS.

QUARTZ fibers coated with a layer of some electrical conductor are often used in the construction of delicate electrometers and similar instruments and it is convenient to be able to prepare them with certainty and ease. The method usually employed to secure a conducting layer depends on the deposition of silver by one of the processes of chemical reduction. For some purposes this method is adequate, but the reduction is difficult to control, the deposit is usually rough and crystalline and the conductivity attained is out of all proportion small for the weight of material deposited. In torsional instruments a thick coating of metal is disadvantageous by reason of the diminution of elasticity entailed. Bestelmeyer[2] reached a satisfactory solution of the problem for such instruments as electrometers through platinizing the fibers by disintegration of a platinum cathode in vacuo. Fibers coated by this method have a very high resistance and are suitable only for electrostatic instruments. Within the last few years the string galvanometer of Einthoven has come into very general use in physiological laboratories. It seems to be less well known among physicists though it has many excellent qualities which would seem to recommend it to a place in the physical laboratory. In this instrument the silvered thread which constitutes the moving system is required to have relatively low resistance—35,000 to a few hundred ohms. It is usually desirable that the fiber be as light as possible for a given conductivity and for some purposes one may wish to limit the air damping which is always a relatively large part of the total damping unless the resistance of the circuit is low. Chemical silvering entails a large air damping due to the roughness of the deposit, and the inertia of a rough thread must be manifestly greater for a given conductivity than it would be if the coating were smooth and coherent. Cannegieter[3] prepared satisfactory fibers for use in the string galvanom-

[1] See preliminary report, PHYS. REV., Vol. 2, Series 2, p. 402, 1913.

[2] A. Bestelmeyer, Leitendmachen von Quarzfäden, Zeitschr. f. Instrumentenk, Vol. 25, p. 339, 1905.

[3] H. G. Cannegieter, Leitendmachen dünner Quarzfäden durch Kathodenzerstaübung mit nachfolgender galvanischer versilberung, Zeitschr. f. Biologische Technik u. Methodik, Vol. 2, p. 21, 1910.

eter by platinizing or silvering them by cathode disintegration and subsequently increasing their conductivity by electroplating with silver. His process involves securing the fiber on the anode of the discharge tube and after the spraying process, transferring it to a glass frame and immersing in a silvering solution with subsequent rinsing. The risk of loss by breakage is naturally increased by so great a number of manipulations. By the process outlined below the necessary conductivity is secured by cathode disintegration alone.

Fig. 1.

Methods of preparing the naked quartz fibers have been described by Boys,[1] Nichols,[2] and Wertheim-Salomonson.[3] I have found a modification of Wertheim-Salomonson's method (which was based on that of Nichols), more satisfactory in the case of extremely fine fibers than the original cross-bow method of Boys. The fibers are collected on frames made of fused silica rod[4] 3 mm. in diameter of the form indicated in Fig. 1. Fused shellac in a thin layer is used to cement the fibers to the frames. A short piece of glass tubing, *A*, Fig. 1, is slipped over the frame. This prevents deposition of silver on the part of the rod covered and in subsequently measuring the resistance of the thread the tube is slid along the rod, insulating the ends of the fiber from each other. The frame is held in the discharge tube by a brass support, also shown in the figure, which permits of adjustment in every direction. Fig. 2 is a schema of the assembled apparatus. The discharge tube is shown at *A*; *B* indicates a liquid air trap and *C* an arrangement for electrolytic generation of hydrogen. The cathode, similar in form to that of Cannegieter, is made of a piece of sheet silver 20 cm. long, 9 cm. wide and .25 mm. thick, bent to a U-shaped section.

The silvering is effected by passing a direct current of about .012 ampere through the tube in an atmosphere of dry hydrogen at a pressure of approximately .2 mm. The current and fall of potential across the tube are kept nearly constant and the pressure varied as may be necessary.

[1] C. V. Boys, On the Production, Properties and Some Suggested Uses of the Finest Threads, Phil. Mag., Vol. 23, 5th Series, p. 489, 1887. Also C. V. Boys, Quartz Fibers, The Electrician, Vol. 38, p. 205, 1896.

[2] Edward L. Nichols, The Galvanometer, Electric Power, Vol. 6, p. 178, 1894.

[3] J. K. A. Wertheim-Salomonson, Anfertigung und Gebrauch dünner Quarzfäden, Zeitschr. f. Biol. Tech. u. Method., Vol. 1, p. 35, 1908.

[4] This rod, which is also used to make the fibers, can be obtained from The Thermal Syndicate, Ltd., 50 East 41st St., New York.

The usual drop across the tube is about 800 volts. Current is supplied by small generators. The discharge tube is made considerably longer than the cathode in order to keep the ground joint well away from the discharge so as to avoid contamination of the tube by the mixture used to lubricate the joint. Extension of the tube well above the cathode delays silvering of the top which would prevent inspection of the interior

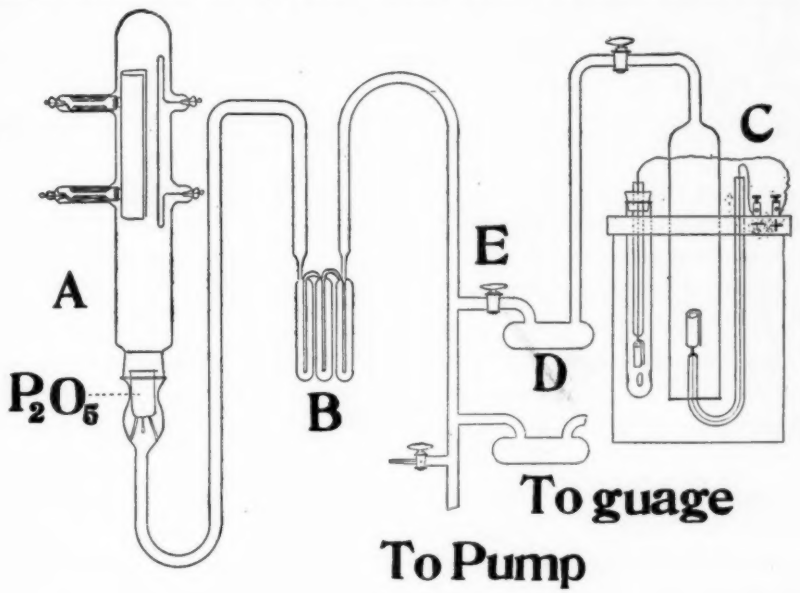


Fig. 2.

after closure. The large volume of the tube is advantageous since the effect of self-evacuation is less troublesome as was pointed out by Stark.[1] In a preliminary report to the Physical Society it was mentioned that large quantities of hydrogen seemed to be occluded. At that time the supporting frames were held in a perforated cork stopper. On substituting the brass holder the rapid disappearance of gas ceased.[2] The vacuum now changes very slowly and admission of small amounts of gas at intervals of 10 minutes or more suffice to maintain the necessary pressure.

It has been shown by Schmidt,[3] that the canal rays exert apparent

[1] J. Stark, Der Kathodenfall des Glimmstromes als Funktion von Temperatur, Stromstärke und Gasdruck, Ann. der Physik, Vol. 12, p. 9, 1903.

[2] Since the above was written this fluctuation of pressure has been shown to be due to a reaction in which hydrogen phosphide is formed from the phosphorus pentoxide used for drying. The reaction seems to be conditioned on the presence of traces of water vapor in the gas and can be produced without the cork stopper by removing the liquid air from the trap.

[3] G. C. Schmidt, Ueber die chemischen Wirkungen der Canalstrahlen, Ann. der Physik. 4th Series, Vol. 9, p. 711, 1902.

oxidizing or reducing influences according to the nature of the gas in the tube. Hydrogen was chosen to secure the reducing effect, though I had presumed an inert gas like nitrogen might be equally good. Recent work by Kohlschütter and Noll,[1] makes it appear likely that hydrogen is preferable for the reason that in it the metal deposits in a more coherent layer. In earlier experiments using as the source of current an induction coil with rectifying valve tubes, uniform deposits were obtained whose conductivity was very slight, though they attained a thickness several times that of the quartz core. This occurred even with gold electrodes in a hydrogen atmosphere. At this time no liquid air trap was used and mercury vapor was undoubtedly present, also probably more water vapor than with the use of the trap. The experiments of Kohlschütter and Noll suggest that the presence of these vapors may have been partly responsible for the result, but the source of current was an important factor, since with a direct current from generators good deposits are often obtained without using the liquid air trap.

Tyndall and Hughes[2] have shown that the rate of disintegration of a cathode for a constant current and cathode fall is constant over a considerable range of pressures. In attempting to secure a definite rate of increase in the conductivity of a fiber so as to be able to judge the time necessary to obtain a desired result, it would be better to measure the cathode fall than to take the drop across the entire tube. However, where the length of the positive glow is comparatively small, the difference between cathode fall and total fall is not great and the uniformity of results secured by maintaining constant current and approximately constant fall of potential across the entire tube has been satisfactory. The time required to produce a given conductivity in a fiber of given dimensions may be best illustrated by a few actual experimental results.

Diameter of Quartz Fiber.	Time of Discharge.	Resistance of 14 Cm. Length.
.0025 mm.	1 hour,	3,020 ohms.
.0025 mm.	1 hour, 30 minutes,	2,400 ohms.
.002 mm.	2 hours,	2,700 ohms.
.0014 mm.	2 hours,	15,000 ohms.
.0013 mm.	3 hours, 13 minutes.	11,200 ohms.

Under the microscope the deposit appears smooth and uniform. No increase in diameter can be measured after silvering, at least not by the

[1] V. Kohlschütter and A. Noll, Ueber feine Metallzerteilungen, Zeitschr. f. Elektrochem., Vol. 18, p. 419, 1912.

[2] A. M. Tyndall and H. G. Hughes, Kathode Disintegration in a Vacuum Tube, Phil. Mag., Vol. 27, p. 415, 1914. For a very complete bibliography of the subject of cathode disintegration from 1852 to 1912, see V. Kohlschütter, Die Zerstaübung durch Kanalstrahlen, Jahrbuch der Radioaktivität und Elketronik, Vol. 9, p. 355, 1912.

microscopic methods at my disposal. Chemically silvered fibers show a distinct increase in diameter for deposits which give them resistances of the order of those in the above table. The silver deposited in the cathode tube must be much more compact and coherent. The resistance per unit length is very uniform and considering the silver as a uniform thin sheet applied to a circular cylinder, one may calculate the thickness from the conductivity. For such a fiber as the last in the table the calculated thickness is 48×10^{-6} mm. This is probably less than the actual thickness, since it is doubtful if the coating is ever as perfectly coherent as the silver in a solid wire.

The durability of the coatings has been good considering their great tenuity. All the fibers have increased in resistance with time. The behavior of several fibers in this respect is tabulated below.

Number of Fiber.	Data.	Resistance, Ohms.
6	Dec. 9, 1913,	2,400
	Dec. 25, 1913,	3,000
	June 27, 1914,	3,390
	August 3, 1914,	3,420
7	Dec. 9, 1913,	3,020
	Dec. 25, 1913,	3,450
	June 22, 1914,	3,750
	August 3, 1914,	3,820
12	June 27, 1914,	15,300
	July 8, 1914,	16,000
	August 3, 1914,	17,140

Using the fibers at maximum tension in the string galvanometer seems to hasten deterioration and on increasing the tension nearly to the breaking point I have seen the silver coating become electrically discontinuous without rupturing the quartz.

The fibers are fastened by soldering to brass tips for insertion in the galvanometer. Ordinary tin-lead solder without flux is satisfactory for chemically silvered fibers, but the heat necessary to melt it seemed at times to injure the cathode silvered threads. I have used Wood's metal for about a year with good results. This alloy does not adhere well to brass, but if the brass is first "tinned" with ordinary solder and a little Wood's metal allowed to melt on the tinned surface before it cools, the soft alloy can be made to adhere subsequently without difficulty. Frequently when fibers cease to conduct it is found that the soldered joint is the point of discontinuity and resoldering is usually possible.

DEPARTMENT OF PHYSIOLOGY,
COLUMBIA UNIVERSITY, NEW YORK,
August, 1914.

NOTE ON THE DIRECT DETERMINATION OF h.

BY O. W. RICHARDSON.

IN a paper published in the PHYSICAL REVIEW, Vol. 4, p. 73 (July, 1914), under the title "A direct determination of h" Professor Millikan submits a resumé of previous experimental work which I venture to think may be misapprehended by those who are insufficiently familiar with the history of this subject. In discussing Einstein's photoelectric equation he points out that it involves the following consequences:

"(1) That there is a linear relation between the frequency of the impressed light and the maximum energy of emission of the electrons ejected by it.

"(2) That the slope of the line representing the linear relation between P.D. and ν is h/e, *i. e.*, that this slope times e is Planck's "h."

"(3) That the intercept of the P.D. line on the ν axis gives the frequency ν_0 at which the metal in question first begins to be photoelectrically active."

He then goes on to state that "The second and third of these assertions have not heretofore been made the subject of accurate test nor can they be so made without simultaneous measurement *in vacuo* of both contact potentials and photo-potentials in the case of metals which are sensitive throughout a long range of frequencies. The spectral lines used in the test must further be strictly monochromatic and of frequency determinable to a high degree of precision."

As regards the first of the three assertions he quotes an opinion of Pohl and Pringsheim as to the inadequacy, for deciding between various alternatives, of the experiments of Hughes and of Richardson and Compton. I shall not enter specifically into the merits of this particular question since the objections raised by Pohl and Pringsheim have already been answered by Professor Hughes.[1]

I should like, however, to be allowed to call attention to the following facts:

1. The three assertions enumerated above form three of the principal

[1] Phil. Mag., Vol. 27, p. 473 (1914).

conclusions drawn by Richardson and Compton[1] from the experiments they describe in the paper to which Professor Millikan refers.

2. In those experiments the contact potentials and photo-potentials were determined *in vacuo* simultaneously. It is true that the method used for getting the contact potentials was a novel one and depends upon the determination of the applied potential difference at which the photo-electric current just becomes saturated. This method had, however, previously been shown to be reliable by the experiments of Compton[2] and its validity has since been confirmed by Page.[3]

3. Although the experiments did not cover so wide a range of frequency in the exciting light, the metals employed include sodium, the one examined by Professor Millikan.

4. So far as monochromatism and definiteness of frequency are concerned there is no doubt that the apparatus used by Richardson and Compton was quite adequate to the purposes of the experiments.

In drawing attention to the facts mentioned above I am far from desiring to disparage Professor Millikan's achievement, the importance of which can hardly be exaggerated. There is no doubt that the work of Kadesch[4] exhibits an improvement in accuracy over the earlier experiments of Hughes and of Richardson and Compton and that Professor Millikan has succeeded in effecting a still greater advance in the same direction. The results of his investigation I am particularly glad to welcome as they are so entirely in agreement with the views which the experiments made in collaboration with Dr. Compton led me to advocate.

[1] Phil. Mag., Vol. 24, p. 575 (1912), Abstract in PHYS. REV., Vol. 34, p. 393 (1912).
[2] Phil. Mag., Vol. 23, p. 579 (1912).
[3] Amer. Journal of Science, Vol. 36, p. 501 (1913).
[4] PHYS. REV., Vol. 3, p. 367 (1914).

TEMPERATURE DISTRIBUTION IN AN INCANDESCENT LAMP FILAMENT IN THE NEIGHBORHOOD OF A COOLING JUNCTION.

BY A. G. WORTHING.

INTRODUCTION.

THE filaments of incandescent lamps are subject to end-losses which result from the cooling effects of supports. These losses are sometimes of considerable magnitude and must be determined if it is desirable to study certain of the properties of the filament. The variations existing near such a cooling junction may, indeed, afford the opportunity for the convenient measurement of certain other properties, such as the thermal conductivity or the Thomson electromotive force, subjects on which the writer hopes to present papers soon. A knowledge of the temperature distribution in such cases is of considerable value.

THEORETICAL CONSIDERATIONS.

The theory which is involved here assumes a homogeneous, cylindrical filament of uniform cross-section and surface condition, in an evacuated chamber, the filament being heated by an electric current which is uniformly distributed over any cross-section. A small amount of speculation leads one to expect, as one proceeds from the cooling junction, a rapid rise in temperature which approaches a maximum value according to some exponential law. The isothermal surfaces within might be expected to be somewhat similar to portions of paraboloids of revolution belonging to a family whose axis is the axis of the filament. The fundamental differential equation as used here is an expression in cylindrical coordinates stating that, for the condition of a steady state, the net rate of conduction of heat into a small element of such a filament plus the rate of development of heat electrically within it equates to zero. Consider a hollow cylindrical element of such a filament of length Δl, of radius r and of radial thickness Δr, whose axis coincides with the axis of the filament. There follows:

$$(1)\quad 2\pi r\left[k\frac{\partial^2 T}{\partial l^2}+\frac{dk}{dT}\left(\frac{\partial T}{\partial l}\right)^2\right]\Delta l\Delta r+2\pi r\left[k\frac{\partial^2 T}{\partial r^2}+\frac{k}{r}\frac{\partial T}{\partial r}+\frac{dk}{dT}\left(\frac{\partial T}{\partial r}\right)^2\right]\Delta l\Delta r+2\pi r i^2\rho\Delta l\Delta r=0.$$

The meanings of the above symbols together with others to be used later are given in Table I. The first, second and third terms represent respectively the net rate of heat conduction into the element of volume through the ends, the net rate of heat conduction into the element of volume radially, and the rate of heat production in the element of volume electrically. (1) leads directly to

$$(2) \qquad \frac{\partial^2 T}{\partial l^2} + \frac{\partial^2 T}{\partial r^2} + \frac{1}{r}\frac{\partial T}{\partial r} + \frac{1}{k}\frac{dk}{dT}\left[\left(\frac{\partial T}{\partial l}\right)^2 + \left(\frac{\partial T}{\partial r}\right)^2\right] + \frac{i^2\rho}{k} = 0.$$

TABLE I.

T	Temperature.
l	Distance parallel to filament axis measured from the cooling support.
r	Radial distance.
ρ	Resistivity.
k	Thermal conductivity.
i	Current density.
r_0	Radius of the filament.
T_0	Temperature at the filament surface.
T_{0m}	Maximum surface temperature.
k_m	Thermal conductivity at the maximum filament temperature.
k', T', T_0', T_{0m}'	Quantities similar to k, T, T_0, T_{0m} in a system where $(dk'/dT') = 0$.
c, a, μ, l_0, ν, A	Constants whose meanings will be defined later.

(2) may be changed to a more suitable form by assuming a scale of temperature T', in which

$$(3) \qquad \frac{dk'}{dT'} = 0;$$

we then have

$$(4) \qquad \frac{\partial^2 T'}{\partial l^2} + \frac{\partial^2 T'}{\partial r^2} + \frac{1}{r}\frac{\partial T'}{\partial r} + \frac{i^2\rho}{k'} = 0.$$

In case

$$(5) \qquad \frac{i^2\rho}{k'} = a^2 T'$$

we finally have

$$(6) \qquad \frac{\partial^2 T'}{\partial l^2} + \frac{\partial^2 T'}{\partial r^2} + \frac{1}{r}\frac{\partial T'}{\partial r} + a^2 T' = 0.$$

By means of the well-known device of assuming

$$(7) \qquad T' = RL,$$

where R and L are respectively functions only of r and of l, two independent equations may be obtained from (6):

$$(8) \qquad \frac{d^2 L}{dl^2} - \mu^2 L = 0,$$

$$\frac{d^2R}{dr^2} + \frac{1}{r}\frac{dR}{dr} + (\mu^2 + a^2)R = 0, \tag{9}$$

where μ^2 is a constant.

There are three boundary conditions which must be fulfilled.

$$\left[\frac{T'}{T_{0m}'} = \frac{J_0(ar)}{J_0(ar_0)}\right]_{l=\infty}, \tag{10}$$

where J_0 represents a Bessel function of zero order.

$$\left[\frac{T'}{T_{0m}'} = f(l)\right]_{r=r_0}, \tag{11}$$

$$\left[\frac{T'}{T_{0m}'} = F(r)\right]_{l=0}. \tag{12}$$

The first of these only is theoretical and merely states the particular solution of (6) for the condition of no conduction of heat along the filament, a condition which is fulfilled at a considerable distance from a cooling junction. The second boundary condition gives the surface temperature distribution. It is necessarily one that must be experimentally determined. The third boundary condition naturally specifies the temperature distribution across some surface near the cooling junction. In practice this distribution must be assumed.

In case $f(l)$ is expressed in terms of a hyperbolic sine or a hyperbolic cosine series, a solution may be obtained which represents accurately the distribution of temperature by means of an infinite series whose terms are of the type

$$A \sinh(\mu l)\, J_0(\sqrt{\mu^2 - a^2}\,\sqrt{-1}\,r).$$

In case $f(l)$ is expressed in terms of an exponential series, as has been done by the writer for some of his determinations, an expression may be obtained for the temperature distribution which although it theoretically fails under certain conditions, represents the temperature distribution to a high degree of accuracy in all practical cases which the writer has considered. Assume thus the following solution of (8)

$$f(l) = 1 - A_1 e^{-\mu(l+l_0)} + A_2 e^{-2\mu(l+l_0)} - \cdots, \tag{13}$$

where l_0 is a constant depending on the materials and dimensions at the cooling support and on the conditions of operation. For $F(r)$ in practice one can not, as already stated, make any experimental determination. It is evident from simple considerations and from the later determinations of temperature difference between filament axis and filament surface that such an assumption as

$$F(r) = \text{const.} \tag{14}$$

is warranted. A double series suffices to give the resultant temperature distribution.

$$\frac{T'}{T_{0m}'} = S_1 + S_2 = \frac{J_0(ar)}{J_0(ar_0)} - A_1 e^{-\mu(l+l_0)} \frac{J_0(\sqrt{\mu^2 + a^2}\, r)}{J_0(\sqrt{\mu^2 + a^2}\, r_0)}$$

$$(15) \quad + A_2 e^{-2\mu(l+l_0)} \frac{J_0(\sqrt{(2\mu)^2 + a^2}\, r)}{J_0(\sqrt{(2\mu)^2 + a^2}\, r_0)} - \cdots + B_1 e^{-\nu(l+l_0)} J_0(\sqrt{\nu_1^2 + a^2}\, r)$$

$$+ B_2 e^{-\nu_2(l+l_0)} J_0(\sqrt{\nu_2^2 + a^2}\, r) - \cdots,$$

where $B_1, B_2 \cdots \nu_1, \nu_2 \cdots$ represent undetermined constants. If $\nu_1, \nu_2 \cdots$ be considered particular values of μ, it is readily seen that each term of (15) is a solution of (8) and of (9) and therefore of (6). The second of the two series S_2 in (15) represents a correction term which enters, due to the failure of the first series S_1 by itself to fulfill the boundary condition (14). In determining the constants of S_2 it is to be considered as a separate series. Its boundary conditions as such, since the first two of the three main boundary conditions are fulfilled by S_1, are

$$(16) \qquad [S_2 = 0]_{l=\infty},$$

$$(17) \qquad [S_2 = 0]_{r=r_0},$$

$$(18) \qquad [S_2 = -S_1]_{l=0}.$$

The method of evaluating the constants here may be found in appropriate texts dealing with Bessel's functions.[1] It is of course necessary to first evaluate S_1 for the position $l = 0$. Evidently the sum of S_1 and S_2 fulfills the boundaries (10), (11) and (12).

The most satisfactory comprehension of a temperature distribution results from a consideration of $1/T_{0m}'\ \partial T'/\partial l$ and $1/T_{0m}'\partial T'/\partial r$ and through them of the axial and the radial components of the temperature gradient $\partial T/\partial l$ and $\partial T/\partial r$ and of the angle which the temperature gradient makes with the axis of the filament. Differentiation of (15) gives

$$(19) \quad \frac{1}{T_{0m}'}\frac{\partial T'}{\partial l} = A_1\mu e^{-\mu(l+l_0)} \frac{J_0(\sqrt{\mu^2 + a^2}\, r)}{J_0(\sqrt{\mu^2 + a^2}\, r_0)} - 2A_2\mu e^{-2\mu(l+l_0)} \frac{J_0(\sqrt{(2\mu)^2 + a^2}\, r)}{J_0(\sqrt{(2\mu)_2 + a^2}\, r_0)} + \cdots$$

and

$$(20) \quad \frac{1}{T_{0m}'}\frac{\partial T'}{\partial r} = \frac{\partial/\partial r\ J_0(ar)}{J_0(ar_0)} - A_1 e^{-\mu(l+l_0)} \frac{\partial/\partial r\ J_0(\sqrt{\mu^2 + a^2}\, r)}{J_0(\sqrt{\mu^2 + a^2}\, r_0)} + \cdots$$

For computations using (19) and (20) often the quantities represented

[1] Byerly's Fourier's Series and Spherical Harmonics, p. 228.

by Bessel's functions may be taken as unity, while for expressions such as $\partial/\partial r\ J_0\ (cr)$ may be taken the approximation,

$$\frac{\partial}{\partial r}J_0(cr) \doteq -cJ_1(cr) \doteq -\frac{c^2r}{2}\ . \tag{21}$$

The method of procedure for obtaining the corresponding values for $\partial T/\partial l$ and $\partial T/\partial r$ will be evident when the relation between T and T' is once determined.

THE SURFACE TEMPERATURE DISTRIBUTION.

The method of study was based on the Holborn-Kurlbaum optical pyrometer principle and is very similar to that employed by Hyde, Cady and Worthing[1] in a study of energy losses in electric incandescent lamps and by the writer in a study of the variations from Lambert's cosine law.[2] All of the precautions which have been enumerated by Worthing and Forsythe[3] were made use of. The arrangement of apparatus is shown in Fig. 1. The filaments studied were of tungsten mounted

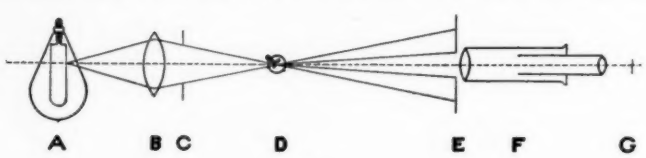


Fig. 1.

Diagram showing arrangement of apparatus. *A*, background; *B*, objective lens; *C*, entrance cone diaphragm; *D*, pyrometer filament; *E*, eyepiece diaphragm; *F*, eyepiece; *G*, monochromatic glass filter.

as U-shaped loops in evacuated bulbs. The lamps, which were well aged in order to remove gases, were located at A. The necessary measurements consist in balancing in brightness the pyrometer filament D against the background filament A in the neighborhood of the cooling junction as that filament, heated to incandescence by a constant current, is raised or lowered. Next with exactly the same arrangement of apparatus, excepting that a black body is substituted at A, and is operated at various temperatures, a calibration of the pyrometer filament current as a function of the black body temperature of the background is obtained. Then with the aid of a black body temperature—true temperature calibration of the background filament, taking account of the glass of the bulb of the lamp placed at A, one easily obtains the surface temperature distribution along the filament placed at A. The writer, however, used

[1] Trans. of Ill. Eng. Soc. (U.S.), 6, p. 238, 1911. Illum. Eng. (Lond.), 4, p. 389, 1911.

[2] Astrophys. Jour., 36, p. 345, 1912.

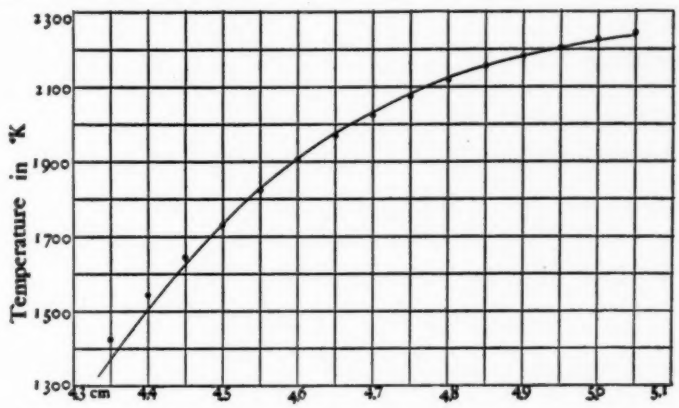
[3] PHYS. REV. II, 4, p. 163 (1914).

a somewhat more roundabout method in this work, due to his interest in certain other considerations. The effects of the Thomson electromotive force were eliminated by averaging the results as to temperature distribution obtained with direct currents flowing through the filament first in one direction then in the opposite direction. The black-body temperature—true temperature calibration used was that obtained by Mendenhall and Forsythe.[1]

As has already been stated an exponential series relation between surface temperature and distance was found,[2]

$$(22) \qquad \frac{T_0}{T_{0m}} = [1 - e^{-\mu(l+l_0)}]^n = 1 - ne^{-\mu(l+l_0)} + \frac{n(n-1)}{2} e^{-2\mu(l+l_0)} - \cdots.$$

How nearly this represents the distribution experimentally obtained in a particular case may be seen from Fig. 2. The average of a great



Distance along the filament in cm. from an arbitrarily chosen zero.

Fig. 2.

number of such determinations has shown all of the deviations to be noticed, with one exception, to be accidental. Deviations in a direction to make the computed value of T_0/T_{0m}, too small in the immediate neighborhood of the cooling junction always occur. They may result from a noticeable progressive change in the surface condition as one proceeds toward the junction. These deviations are neglected in this paper. Measurements on several different sized filaments operated at different maximum temperatures, indicate that n is constant throughout and that μ varies so that

$$(23) \qquad \frac{i}{\mu} = \text{constant (approx.)}$$

[1] Astrophys. Jour., 37, p. 380, 1913.

[2] See following paper.

The deviation from constancy occurs only with a change in the maximum operating temperature, the ratio decreasing slightly with decreasing maximum temperatures. For the case of a change in μ due only to a change in filament size, (23) may be shown, on assuming the same general surface distribution in the two cases, to be theoretically true. Of two filaments of radii r_1 and r_2 operated at the same maximum temperature, consider two corresponding elements of filament of equal length and the same mean temperature. We have for both elements the identity,

(24) Electrical input = radiation output + conduction output.

Consequently

$$(25)\quad \pi r_1^2 \Delta l\, i_1^2 \rho = 2\pi r_1 \Delta l f(T) + \pi r_1^2 \Delta l \left[k \left(\frac{\partial^2 T}{\partial l^2}\right)_1 + \frac{dk}{dT}\left(\frac{\partial T}{dl}\right)^2_1 \right],$$

$$(26)\quad \pi r_2^2 \Delta l\, i_2^2 \rho = 2\pi r_2 \Delta l f(T) + \pi r_2^2 \Delta l \left[k \left(\frac{\partial^2 T}{\partial l^2}\right)_2 + \frac{dk}{dT}\left(\frac{\partial T}{\partial l}\right)^2_2 \right],$$

where $f(T)$ represents the radiation intensity.
The well-known relation

$$(27)\quad \left[\frac{i_1}{i_2} = \left(\frac{r_2}{r_1}\right)^{\frac{1}{2}} \right]_{T_1 = T_2},$$

When combined with (25) and (26) gives

$$(28)\quad \frac{r_2}{r_1} = \frac{\left(\frac{\partial^2 T}{\partial l^2}\right)_1 + \frac{1}{k}\frac{dk}{dT}\left(\frac{\partial T}{\partial l}\right)^2_1}{\left(\frac{\partial^2 T}{\partial l^2}\right)_2 + \frac{1}{k}\frac{dk}{dT}\left(\frac{\partial T}{\partial l}\right)^2_2}.$$

If for filament 1 we have

$$(29)\quad T_1 = f_1(l),$$

and for filament 2 the assumed same general surface distribution such that

$$(30)\quad \left[T_2 = f_2(l) = f_1\left(\frac{\left(\frac{\partial T}{\partial l}\right)_2}{\left(\frac{\partial T}{\partial l}\right)_1} l \right) \right]_{T_1 = T_2},$$

there follow

$$(31)\quad \frac{\left(\frac{\partial^2 T}{\partial l^2}\right)_1}{\left(\frac{\partial^2 T}{\partial l^2}\right)_2} = \frac{\left(\frac{\partial T}{\partial l}\right)^2_1}{\left(\frac{\partial T}{\partial l}\right)^2_2}$$

and

$$\left(\frac{\partial T}{\partial l}\right)_1 i_2 = \left(\frac{\partial T}{\partial l}\right)_2 i_1. \tag{32}$$

When $f(l)$ has the form given in (22), (23) results.

This relation is important in that it enables one to go directly from a surface distribution for one filament operating at a definite maximum temperature to that of another filament operating at the same maximum temperature.

THE T' SCALE OF TEMPERATURE.

Results on the thermal conductivity of tungsten[1] indicate that

$$k = k_m + C_1(T - T_m). \tag{33}$$

The new temperature scale T' having the necessary condition (3) of constant thermal conductivity was further arbitrarily fixed by making

$$k' = k_m \tag{34}$$

and

$$[T' = 0]_{T=0}. \tag{35}$$

Consequently

$$T' = \left(1 - C_1 \frac{T_m}{k_m}\right) T + \frac{C_1}{2k_m} T^2. \tag{36}$$

The substitution of (22) in (36) gives the previously assumed relation (13) in which A_1, A_2, etc., are functions only of n and of the coefficients of (36).

APPLICATION OF FOREGOING TO A SPECIAL TUNGSTEN FILAMENT.

The value of certain constants relating to the particular filament used and the coefficients of (22) and (33) are incorporated in Table II.

TABLE II.

Certain Important Constants.

Constant.	Value.	Constant.	Value.
r_0	.01045 cm.	μ	$3.80 \frac{1}{\text{cm}}$
i	$12600 \frac{\text{amp}}{\text{cm}^2}$	n	1.87
ρ_m	75.8×10^{-6} ohms $\times$ cm.	k_m	$1.385 \frac{\text{watts}}{\text{cm} \times \text{deg}}$
T_{0m}	2315°K.	C_1	$5.10^{-4} \frac{\text{watts}}{\text{cm} \times \text{deg}^2}$
l_0	.3 cm (roughly)	a	$2.60 \frac{1}{\text{cm}}$

The value given for a represents an average value for the interval 1500° K. to 2450° K., throughout which range there is a decrease of approximately

[1] See later paper.

10 per cent. in going from the lower to the higher temperature. The assumption of constancy is here allowable in case one is concerned chiefly with the magnitude and the direction of the temperature gradient. In case one is interested in the differences in temperature between the surface and the axis at given cross sections, only values of the right order of magnitude will be obtained. The values thus found, however, will be directly related to the true differences approximately as the square of the a used in the computations is related to the squares of the true values of a for the regions under consideration.

Another method of obtaining the temperature differences consists in computing the distributions for various values of a and then applying to the regions in question the appropriate distributions. This consideration is based on computations which show that, for positions where the axial components of the temperature gradients are large in comparison with the radial components, small changes in the temperature distribution at one cross-section appreciably affect only a very limited region thereabout.

The equation for the special case resulting from (15) is

$$\frac{T'}{T_{0m'}} = S_1 + S_2 = \frac{J_0(2.60r)}{J_0(2.60r_0)} - 3.21e^{-3.8(l+l_0)}\frac{J_0(4.61r)}{J_0(4.61r_0)}$$

$$+3.91e^{-7.6(l+l_0)}\frac{J_0(8.04r)}{J_0(8.04r_0)} - \cdots - 6.4\times 10^{-5}e^{-230(l+l_0)}J_0(230r) + \cdots .^1 \tag{37}$$

As has already been noted, this solution fails under certain conditions,—*e. g.*, when $J_0(\sqrt{\mu^2_n + a^2}\, r_0)$ is zero. In ordinary cases the series in (13) may consist of a finite number of terms so terminated that this condition is impossible. The first term only of S_2 in (37) produces any noticeable effect on the temperature distribution.

The most interesting results for a particular application based on a constant value for a are indicated in Table III.

On account of a slightly different relation obtained for k as a function of T in the preliminary work published in an abstract,[1] values there given will not be found to be entirely consistent with those here given.

The formation of an expression for $\partial T'/\partial r$ from the S_1 terms of (37) shows that it, so far as first order terms are concerned, is proportional to the radial distance. Evidently also at any cross-section

$$\frac{\partial T}{\partial r} = -C_2 r, \tag{38}$$

where C_2 is a constant. Integration gives

[1] PHYS. REV., II., 3, p. 67 (1914).

TABLE III.

Temperature Distribution Results in a Filament of Tungsten (r_0=0.01045 cm.) Heated to a Maximum Temperature of 2315° K.

l	T_0	Relative Emission Intensity.	Temperature Gradient at Surface.			Temperature Difference Between Axis and Surface.
			Radial Component.	Axial Component.	Angle Made with Filament Axis.	
0.0 cm	1149°K	0.023	0 $\frac{\text{deg}}{\text{cm}}$	3750 $\frac{\text{deg}}{\text{cm}}$	0.0°	0.00°
0.2	1711	.200	15	2130	0.3	.08
0.5	2114	.619	31	756	2.3	.16
0.7	2225	.808	39	364	6.1	.20
1.2	2301	.967	46	54.7	40	.24
1.7	2314	.9952	47	8.3	80	.25
∞	2315	1.0000	47	0.0	90	.25

$$T - T_0 = \frac{C_2}{2}(r_0^2 - r^2). \tag{39}$$

Therefore

$$[T - T_0]_{r=0} = \frac{C_2}{2} r_0^2 = -\frac{r_0}{2}\left(\frac{\partial T}{\partial r}\right)_{r=r_0}. \tag{40}$$

Equation (40) was used in computing the last column of Table III. It readily follows with slight approximation that the isothermal surfaces are portions of paraboloids of revolution which become more and more convex toward the cooling junction as one recedes along the filament from it. Further (39) and (40) show that the difference in temperature between a point on the axis and another point on the same cross-section varies as the square of the radial distance.

When, however, corresponding points on two filaments of the same material but of different radii and operated at the same maximum temperature, are compared, (23) together with the derivative $\partial T'/\partial r$, which may be obtained with the aid of (20), indicate that the differences in temperature, particularly when not too far from the maximum temperature, between corresponding axial points and other points on the same cross-section vary as the radii of the filaments. This fact would appear as evident from the equation given by Angell[1] for the portion of the filament where the temperature gradient is wholly axial.

A close approximation to the temperature distribution in a tungsten filament near a cooling junction for a certain definite heating current, when once the distribution is known for some other heating current may likewise be obtained quite simply. A consideration of (19) in which the coefficients A_1, A_2, etc., are practically constant shows, for corresponding

[1] PHYS. REV., 33, p. 421 (1911).

points chosen from the standpoint of T_0'/T_{0m}', that the expression $1/T_{0m}'\ \partial T'/\partial l$ varies as μ, which in turn according to (23) varies as i. The axial components of the temperature gradient may evidently be everywhere determined for the unknown surface distribution. The variation in $1/T_{0m}'\ \partial T'/\partial r$ may be obtained from similar considerations By (5) we see that a varies as i. From (20) and (21) we see that each term of $1/T_{0m}'\ \partial T'/\partial r$ and that therefore the quantity as a whole, since both a and μ vary as i, varies as i^2. The deviations mentioned in both (5) and (23) are such as to counteract each other. An accurate knowledge of the temperature distribution for one tungsten filament, together with the above considerations will enable one to determine quite accurately the distribution in any case for a filament of the same material.

SUMMARY.

A solution has been obtained which represents with considerable accuracy the temperature distribution in a cylindrical tungsten filament of uniform cross-section and surface condition, heated electrically in an evacuated chamber.

This solution has been applied to a special case in which a tungsten filament (radius = 0.01045 cm.) is heated by a current to a maximum central temperature of 2315° K. (See Table III.)

The method of obtaining from the known distribution the temperature distribution in another filament of the same material, but of different radius heated under the same conditions to the same maximum temperature, is indicated.

The method of obtaining from the known distribution the temperature distribution in the same filament heated under the same conditions to a different maximum temperature is also indicated.

The surface temperature distribution for a tungsten filament for a given case and the approximate laws of variation with changes in filament size and maximum operating temperature have been experimentally determined. See equations (22) and (23).

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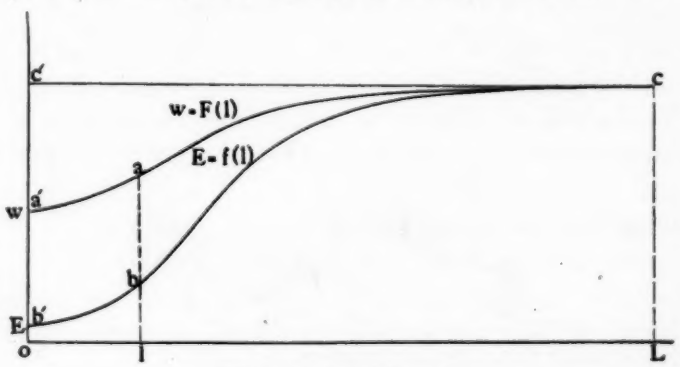
THE THERMAL CONDUCTIVITIES OF TUNGSTEN, TANTALUM AND CARBON AT INCANDESCENT TEMPERATURES BY AN OPTICAL PYROMETER METHOD.

By A. G. Worthing.

Introduction.

THE present paper is the direct outcome of a study of the energy losses in incandescent lamps by Hyde, Cady and Worthing.[1] With a single exception the question of thermal conductivity at incandescent temperatures seems not to have been attempted heretofore. Angell,[2] using a method suggested by Mendenhall, investigated aluminum and nickel up to temperatures of 600° C. and 1200° C. respectively. The temperature measurements were made by means of thermocouples located on the inner and the outer surfaces of hollow cylindrical rods which were electrically heated. Extremely large heating currents and fairly large specimens of material were, of course, necessitated. The question of incandescence did not enter in the method. In the present paper a method of measuring thermal conductivity depending on the incandescence of small filaments mounted in evacuated chambers, such as filaments in ordinary lamp bulbs, is described and made use of.



Distance along filament.

Fig. 1.

Diagram to illustrate method for detemining thermal conductivities.

[1] Trans. Illum. Eng. Soc. (U.S.), 6, p. 238 (1911); Illum. Eng. (Lond.), 4, p. 389 (1911).
[2] Phys. Rev., 33, p. 421 (1911).

THEORY.

Consider the energy supply and radiation intensity distributions per unit of filament surface for a small filament of uniform surface and cross section, mounted in an evacuated bulb and heated to a steady state of incandescence by an electric current. These quantities, w and E respectively, as functions of the distance along the filament are diagrammatically represented by the curves $a'ac$ and $b'bc$ respectively of Fig. 1. The meanings of the symbols here used together with others are given in Table I. Evidently at the center of the filament loop where there is

TABLE I.

Symbols and Quantities Used.

Symbol.	
w	Rate of heat production electrically at a given filament cross-section per unit of radiating surface.
E	Radiation intensity, or rate of radiation of energy per unit of radiating surface.
l	Distance measured along the filament.
L	One half of the filament length.
dH/dt	Rate of conduction of heat along the filament.
r	Radius of filament.
k	Thermal conductivity.
T	Temperature.
i	Current density.
ρ	Resistivity.
$\varkappa$	Electrical conductivity.
w_m, E_m, T_m	Values of w, E and T at center of filament loop.
μ, σ, β, γ, A, and B.	Constants defined by equations (8), (9) and (10).

no temperature gradient along the filament

$$[w = E = w_m = E_m]_{l=L}. \tag{1}$$

It is easily seen that the areas *lacLl*, *lbcLl* and *bacb* respectively represent quantities proportional to the rate of heat production in the filament length lL, the rate of radiation of energy from the filament length lL, and the rate of heat conduction along the filament at l. For the last named quantity, *i. e.*, $\frac{dH}{dt}$, we may write

$$\frac{dH}{dt} = 2\pi r E_m \int_l^L \left(\frac{w}{w_m} - \frac{E}{E_m}\right) dl. \tag{2}$$

This together with the general equation

$$\frac{dH}{dt} = \pi r^2 k \frac{dT}{dl} \tag{3}$$

enables one to write for the thermal conductivity at l

$$k = \frac{2E_m}{r\dfrac{dT}{dl}} \int_1^L \left(\frac{w}{w_m} - \frac{E}{E_m} \right) dl. \tag{4}$$

This assumes that the radial component of the temperature gradient at l is negligible in comparison with the axial component. Determinations of k for different positions l and hence for different temperatures T lead to the determination of k as a function of T.

APPARATUS AND METHOD.

The arrangement of apparatus and the general method of procedure were the same as those described in the study of the temperature distribution in an incandescent lamp filament near a cooling junction.[1] The filaments studied were U-shaped lamp filaments mounted with welded junctions in large well-exhausted lamp bulbs. The lamps which were initially well aged were used as backgrounds. The pyrometer filaments were of tungsten, sufficiently small, usually about 0.025 mm. in diameter, so that even when seen projected against the background at a place where the axial temperature gradient was a maximum, there was no apparent difference in the brightness of the background at the two edges of the projected pyrometer filament.

The precautions noted for optical pyrometric methods of this type by Worthing and Forsythe[2] have been carefully observed in the work on tungsten. The work on tantalum and carbon is less accurate; and while at the time of the experimental work on them all of these precautions were not known, it is believed that the conditions were not such as to cause very great errors.

The experimental work consisted in determining the following three relations,

$$E = \varphi(T), \tag{5}$$

$$E = f(l), \tag{6}$$

$$w = F(l). \tag{7}$$

Equation (5) was obtained by balancing the pyrometer filament first against a central portion of the loop of the filament under investigation when operated successively at various currents, and then against a black body similarly placed and operated at various temperatures. In the former case the brightness of the background image was so reduced by sectored disks that the pyrometer filament currents were of the same order of magnitude in both instances. With the aid of ordinary electrical

[1] PHYS. REV., Vol. IV, No. 6.

[2] PHYS. REV., II, 4, p. 163 (1914).

and length measurements on the background lamp filament, one may then express E as a function of the black body temperature. The temperature relations determined by Mendenhall and Forsythe[1] were used to convert these into the desired functions of the true temperatures.

Equations (6) and (7) were determined in much the same manner that T as a function of l was determined in the paper on temperature distribution already mentioned. In fact (5) enables one to obtain (6) from the temperature distribution there given. The simple determination of the relation between ρ and E with the aid of (6) leads to (7), since obviously w is proportional to ρ everywhere in a uniform filament heated to a steady state by an electric current. The relations (6) and (7) are those represented in Fig. 1 respectively by the curves $b'bc$ and $a'ac$.

The effects of a Thomson electromotive force located in the filaments near the junction were eliminated by averaging the results obtained with the heating current flowing first in one direction through the filament and then in the reversed direction. In determining (5) account was taken of the fact that the average rate of energy supply electrically per unit surface of filament does not equal (less than, as represented in Fig. 1) the rate of energy radiation per unit surface of filament at a point remote from the filament junction. The correction factor is the ratio (area $a'c'ca'$)/(area $Oa'cLO$).[2]

Once given (5), (6) and (7) a method of applying (4) in order to determine k is obvious. Considerable difficulty was experienced in obtaining satisfactory relations for (6), due for the most part to the inability to realize the fundamental assumptions of uniform filament surface and cross-section. The fact that the glass of the bulb enclosing

[1] Astrophys. Jour., 37, p. 380 (1913).

[2] The area $a'c'ca'$ represents an input loss. For many purposes this loss may be considered as producing an apparent decrease in the effective length of the filament ΔL_1 given by (area $a'c'ca'$)/(length oc'). Similarly from the standpoint of the energy radiated, there is an apparent decrease in the effective length ΔL_2, given by (area $b'c'cb'$)/(length oc'). In a like manner one may obtain from the standpoint of the luminous flux from the filament, the apparent decrease ΔL_3. For uniform tungsten filaments, in loops sufficiently long so that there is no sensible heat conduction along the filament at the centers of the loops, there have been found in practice an approximately constant ratio between the junction temperatures, when fused with copper, and the maximum filament temperatures. For such cases general formulæ may be derived for ΔL_1, ΔL_2 and ΔL_3. Thus

$$\Delta L_1 \cdot i = 2700 \frac{\text{amps}}{\text{cm}}$$

where i is the current density L_1 and L_2 are approximately thereafter determined by

$$\Delta L_1 : \Delta L_2 : \Delta L_3 = 3 : 7 : 10.$$

For the lamp mentioned in the main article, operating at 2315° K., the apparent decreases for each junction are respectively 0.21 cm., 0.50 cm. and 0.71 cm.

the background was not optically good was also a source of error. However, as nearly as possible the law was empirically determined for the finite range $0.2 < (E/E_m) < 0.85$ and then assumed to hold also for the range $0.85 < (E/E_m) < 1.00$. Slight errors in pyrometer balancing in this region were always productive of comparatively great errors in the constants of the law sought. Measurements made there, however, always on the whole justified the assumption. Below $E/E_m = 0.2$ deviations from the empirical law found for the middle region always occurred in a definite direction, hence the limits chosen. No values obtained for k were based on the application of the empirical equation to regions where $E/E_m < 0.2$. How well the empirical law fills the requirements may be seen in Fig. 2, in which there have been platted the data

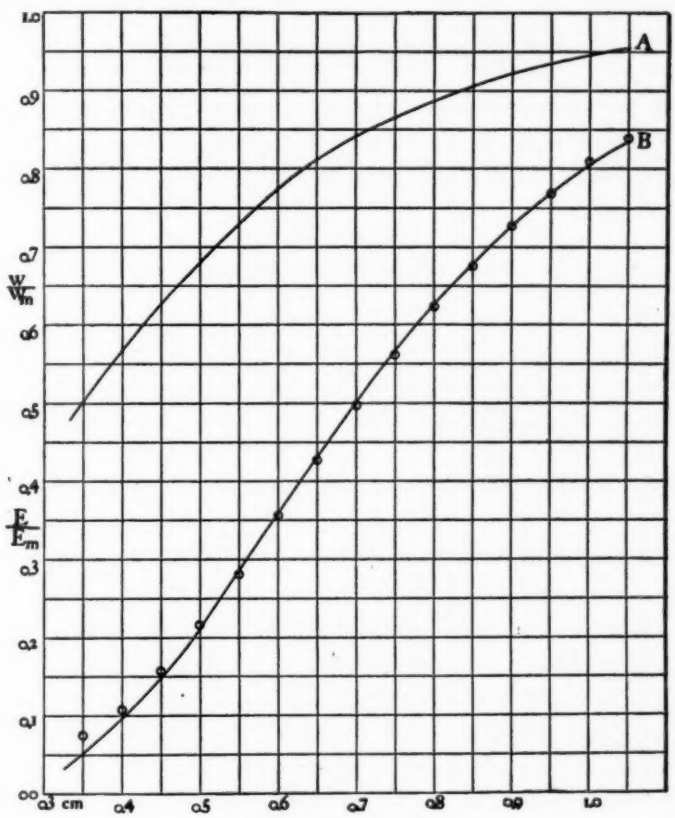


Fig. 2.

The relative input (A) and the relative radiation intensity (B) distributions for a tungsten filament ($r = 0.01045$ cm.) heated to a maximum temperature of 2315° K. The circles represent experimental values of radiation intensities obtained in a particular set of measurements. The curves represent distributions given by equations (9) and (10).

for a single experimental determination of the E and w distributions for the same lamp operated at the same maximum temperature as the one for which the temperature distribution has been given in a paper already referred to. The deviations, with the exception of the ones for small values of E/E_m, are accidental and in the average of many curves are eliminated.

RESULTS.

For tungsten the empirical relations found which determine the character of the functions in (5), (6) and (7) are of the types

$$E = \sigma T^{\beta}, \tag{8}$$

$$\frac{E}{E_m} = [1 - e^{-\mu(l+l_0)}]^{\gamma}, \tag{9}$$

$$\log \frac{w}{w_m} = \log \frac{E}{E_m}\left(A + B \log \frac{E}{E_m}\right). \tag{10}$$

Equations (8) and (10) seem to be quite exact. The values of various constants which enter in connection with the data platted in Fig. 2 in the application of (4) to the determination of k are given in Table II.

TABLE II.

Constants for a Particular Application of (4) *to a Tungsten Filament.*

Quantity.	Value.	Quantity.	Value.
r	0.01045 cm.	β	5.35
i	$12600 \frac{\text{amp}}{\text{cm}^2}$	σ	$6.2\times10^{-17} \frac{\text{watts}}{\text{cm}^2\times\text{deg.}^{5.35}}$
E_m	$62.1 \frac{\text{watts}}{\text{cm}^2}$	γ	10.
T_m	2315° K	A	0.257
μ	$3.80 \frac{1}{\text{cm}}$	B	0.015

The value obtained for β, while probably fairly exact, is to be regarded as preliminary. It is hoped that a future paper from this laboratory will consider it along with other similar determinations in detail. In Fig. 3 there are given the results obtained by the application of (4) to the particular filament when operated at four different maximum temperatures. For each such maximum temperature four determinations have been made of k at various temperatures corresponding respectively to values for E/E_m of 0.8, 0.6, 0.4 and 0.3. That the assumption made in the derivation of (4), of a negligible difference between the temperature gradient and its axial component is justified for these positions, may be seen from an inspection of Table III. of the paper on temperature distribution. In the case of $l = 0.7$ cm., or $E/E_m = 0.808$, at the

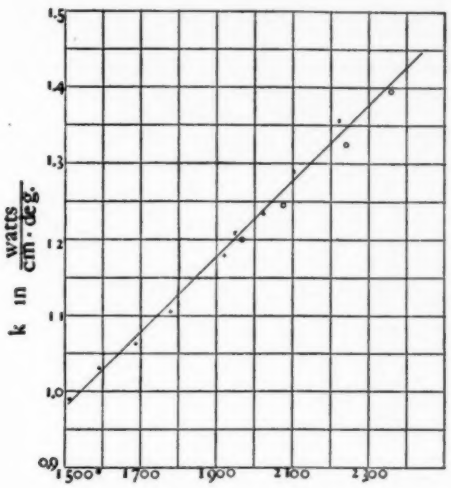


Fig. 3.

Thermal conductivity of tungsten as a function of temperature.

o	14280 $\frac{\text{amp}}{\text{cm}^2}$	2468° K
x	12600	2315
x	10520	2111
.	8420	1890

surface of the filament the temperature gradient is only 0.6 per cent. greater than the axial component. The average over the filament cross section would naturally give a still smaller variation. In case the empirical distributions (9) and (10) are correct, no errors are introduced in the values of k thus determined, due to the fact that as E/E_m approaches unity, the axial component of the temperature gradient is no longer approximately equal to the whole gradient. The general agreement of the results is quite satisfying.

Values of k at various temperatures for tungsten, tantalum and untreated carbon are included in Table III. It is of interest to note that the order in which the materials are given represents their order as to thermal conductivity, tungsten having the highest values; that for carbon there is only a very small temperature coefficient, and that for both tungsten and tantalum there are fairly large positive temperature coefficients. With the exception of carbon no published values with which to compare results have been found. Of these only the rough determination of Hansen[1] on carbon electrodes (these carbon electrodes probably contain carbon in much the same form as do the untreated carbon filaments used by the writer) are directly comparable, since the

[1] Trans. of Amer. Electrochem. Soc., 16, p. 351 (1909).

TABLE III.

Thermal Conductivities k, and Values of $\frac{k}{xT}$ for Tungsten, Tantalum and Carbon in the Range 1500° K. to 2500° K.

Temperature, ° K.	Tungsten		Tantalum.		Carbon (Untreated).	
	k, $\frac{\text{watts}}{\text{cm}\times\text{deg}}$.	$10^{-8}\times\frac{k}{xT}$, C.G.S. Units.	k, $\frac{\text{watts}}{\text{cm}\times\text{deg}}$.	$10^{-8}\times\frac{k}{xT}$, C.G.S. Units	k, $\frac{\text{watts}}{\text{cm}\times\text{deg}}$.	$10^{-8}\times\frac{k}{xT}$, C.G.S. Units.
1500	0.98	0.283		1.62		
1700	1.08	.322	0.73	3.3	0.084	11.9
1900	1.18	.362	.78	3.4	.086	10.1
2100	1.28	.405	.83	3.6	.088	8.8
2300	1.38	.450				
2500	1.48	.502				

others have experimented on the crystalline forms graphite and diamond. Hansen's results give as an average about 0.06 watts/cm. × deg. for the neighborhood 0° C. to 400° C., which is qualitatively in good agreement with the writer's values. He also mentions a value of about 0.008 watts/cm. × deg. for carbon at 3000° C. This does not check at all with the writer's values.

Because of the theoretical interest, determinations have been made of the function k/xT. Its values for all three substances for certain temperatures have been included in Table III. It is of interest to note that k/xT is not approximately constant for any one of them, there being a large negative temperature coefficient for carbon and large positive coefficients for both tungsten and carbon. Variations of a similar character for nickel and aluminum at high temperatures are indicated by the work of Angell,[1] although attention has not been called to them in his paper. Aluminum and nickel respectively have a large positive and a large negative temperature coefficient for k/xT. These deviations have an important theoretical bearing. The classic work of Jaeger and Diessehorst[2] on this function between 18° C. and 100° C. has usually been accepted as indicating its probable constancy at least for pure metals at higher temperatures. This conclusion has fitted in well with electronic theories. The work of Lees[3] and later particularly that of Meissner,[4] experimenting at temperatures as low as 20° K., indicated deviations from constancy such as would be consistent with a zero value at absolute zero. Such deviations were found to disappear, however,

[1] PHYS. REV., 33, p. 421 (1911).

[2] Wissensch. Abh. d. Phys. Techn. Reichsanstalt, 3, p. 269 (1900).

[3] Phil. Trans. (A), 208, p. 381 (1908).

[4] Verh. d. Deut. Phys. Gessell., 16, p. 262 (1914)

at the temperatures used by Jaeger and Diesselhorst. Modifications of the electron theories have been made in accord with these deviations. Further modifications are evidently necessary. Some data obtained by the method here used seem to indicate that the thermal conductivity of tungsten may be a function of the current density in the filament. The author hopes to consider this point in more detail.

SUMMARY.

1. A method based on optical pyrometry for obtaining the thermal conductivity of certain solid substances at incandescent temperatures has been described.

2. The thermal conductivities of tungsten, tantalum and carbon in the region 1500° K. to 2500° K. have been obtained. The results on carbon check well with results by Hansen.

3. Values for the function k/xT (k thermal conductivity, x electrical conductivity, T absolute temperature) have been determined for the same substances and for the same temperature ranges. Large temperature coefficients of the function were found, in contradiction to what would be expected from electronic theories.

4. As a preliminary determination of the relation between the radiation intensity E and the absolute temperature T for tungsten, the equation

$$E = \sigma T^{\beta},$$

where $\beta = 5.35$ and $\sigma = 6.2 \times 10^{-17}$ watts/cm.^{2} $\times$ deg.$^{5.35}$, has been found to hold.

The writer is indebted to Messrs. K. Linder, G. Cadisch, A. Shapero and A. Scheel for efficient aid rendered at various times during the course of the experimental work.

NELA RESEARCH LABORATORY,
NATIONAL LAMP WORKS OF GENERAL ELECTRIC COMPANY,
NELA PARK, CLEVELAND, OHIO,
July, 1914.

PROCEEDINGS

OF THE

AMERICAN PHYSICAL SOCIETY.

MINUTES OF THE SEVENTY-THIRD MEETING.

A REGULAR meeting of the Physical Society was held in Fayerweather Hall, Columbia University, New York, on Saturday, October 31, 1914. President Merritt presided at the meeting. The morning session began at 10 o'clock and the following papers were presented:

Some Applications of Simpson's Rule in Integrating Periodic Functions. FREDERICK BEDELL AND RALPH BOWN.

Five Lithium Lines and their Magnetic Separation. NORTON A. KENT.

A Comparison of Stellar Radiometers and Radiometric Measurements on 110 Stars. (By title.) W. W. COBLENTZ.

An Achromatoscope. (By title.) S. R. WILLIAMS.

Electrostatic Measurement of Single Electrode Potentials. ARTHUR W. EWELL.

The Relation Between the Wave-length and Absorption of X-Rays. WILLIAM DUANE.

An Addition to a Theory of Ionization by Impact. H. H. FARWELL.

The Electron Emission from Tungsten Filaments, containing Thorium. IRVING LANGMUIR.

Application of a Theory of Ionization By Impact to the Experiments of Franck and Hertz. BERGEN DAVIS.

Theory of The Flicker Photometer. HERBERT E. IVES AND E. F. KINGSBURY.

Brightness Flicker and Color Flicker in the Flicker Photometer. HERBERT E. IVES AND E. F. KINGSBURY.

Adjourned for lunch at 12.45.

Afternoon Session, 2.15 P. M.

A Direct Method of Determining The Radiant Luminous Efficiency of Light Sources. E. KARRER.

The Emissivity of Metals and Oxides, II; Measurements with the Micropyrometer. G. K. BURGESS AND R. G. WALTENBERG.

The Total Emissivity of Platinum and the Relation Between Total Emissivity and Resistivity. PAUL D. FOOTE.

A Simple Method for Demonstrating and Measuring Anomalous Dispersion. (By title.) S. R. WILLIAMS.

Measurements with the Coolidge Tube. Transformer Characteristics. J. S. SHEARER.

Measurements with the Coolidge Tube; Brightness of Fluoroscopic Screens. J. S. SHEARER.

Physical Photometry with a Thermopile Artificial Eye. HERBERT E. IVES AND E. F. KINGSBURY.

Note on the Construction of a Short Vacuum Gauge. E. KARRER.

The Electric Resolution of the Series Lines in the Mercury Spectrum. GEORG WENDT AND REINHARD A. WETZEL.

The Longitudinal Stark Effect upon Aluminum Doublets. REINHARD A. WETZEL.

New Vapor Lamps and a Preliminary Study of their Spectra in the Schumann Region. FREDERICK A. SAUNDERS.

Graphic Record of the Period and Damping Factor of a Needle Galvanometer. HORATIO B. WILLIAMS.

A Model Illustrating the Relativity Concepts of Einstein. REINHARD A. WETZEL.

Note on the Melting Point of Tungsten. IRVING LANGMUIR.

Adjourned at 4.30.

ALFRED D. COLE,
Secretary.

A COMPARISON OF STELLAR RADIOMETERS AND RADIOMETRIC MEASUREMENTS ON 110 STARS.[1]

BY W. W. COBLENTZ.[1]

IN this paper experiments are described showing that there is but little difference in the radiation sensitivity of stellar thermocouples constructed of bismuth-platinum, and thermocouples of bismuth—bismuth + tin alloy which have a 50 per cent. higher thermoelectric power.

Improvements are described in the method of maintaining a vacuum, by means of metallic calcium, whereby it will be possible to go to the remotest regions for making radiation measurements without carrying an expensive vacuum pump.

This radiometric outfit was used in connection with the 3-foot Crossley reflector at the Lick Observatory, Mt. Hamilton, Calif. Measurements were made on the radiation of 112 celestial objects. This includes measurements on the bright and dark bands of Jupiter (also a pair of his satellites) the rings of Saturn, and a planetary nebula.

Quantitative measurements were made on stars down to the 5.3 magnitude, and high-grade qualitative measurements were made on stars down to the 6.7 magnitude.

[1] Abstract of a paper presented at the New York meeting of the Physical Society, October 31, 1914.

It was found that red stars emit from two to three times as much total radiation as blue stars of the same photometric magnitude.

Measurements were made on the transmission of the radiations from stars and planets through an absorption cell of water. By this means it was shown that, of the total radiation emitted, the blue stars have about two times as much radiation as the yellow stars—and about three times as much radiation as the red stars, in the spectral region to which the eye is sensitive.

A stellar thermocouple and a bolometer were compared, and the former was found to be the more sensitive. The conclusion arrived at is that, from the appearance of the data at hand, greater improvements are to be expected in stellar thermocouples than in stellar bolometers.

The object of the investigation was to obtain some estimate of the sensitivity required in order to be able to observe spectral energy curves of stars. The radiation sensitivity of the present apparatus was such that, when combined with a 3-foot reflecting telescope, a deflection of 1 mm. would have resulted when exposed to a candle placed at a distance of 53 miles. In order, however, to do much successful work on stellar spectral energy curves, a sensitivity 100 times this value is desirable. In other words, assuming that the rays are not absorbed in passing through the intervening space, the radiometric equipment (radiometer and mirror) must be sufficiently sensitive to detect the radiation from a candle removed to a distance of 500 miles. This can be accomplished by using a 7-foot mirror and by increasing the sensitivity of the present radiometer (thermocouple and galvanometer) 20 times. This increase in sensitivity is possible.

Measurements were made to determine the amount of stellar radiation falling upon 1 cm.^{2} of the earth's surface. The value found is so small that it would require the radiations from *Polaris* falling upon 1 cm.^{2}, to be absorbed and conserved continuously for a period of one million years in order to raise the temperature of one gram of water 1° C. If the total radiation from all the stars falling upon 1 cm.^{2} were thus collected and conserved it would require from 100 to 200 years to raise the temperature of one gram of water 1° C. In marked contrast with this value, the solar rays, which reach the earth's surface, can produce the same effect in about one minute.

BUREAU OF STANDARDS, WASHINGTON.

THE EMISSIVITY OF METALS AND OXIDES, II: MEASUREMENTS WITH THE MICROPYROMETER.[1]

BY G. K. BURGESS AND R. G. WALTENBERG.

THE micropyrometer may be used conveniently for the approximate determination of the monochromatic emissivities of metals, oxides, etc., in microscopic quantities at high temperatures. It is possible to determine to one per cent. the emissivity of a mass of 0.01 mg. having an area of

[1] Abstract of a paper presented at the New York meeting of the Physical Society, October 31, 1914.

0.25 mm.² and a thickness of 0.005 mm. The determination of the temperature-coefficient of emissivity is readily made, as well as the detection of variation of emissivity with change of state, as at the melting point.

Assuming the emissivity for solid platinum is 0.33 for red light of wavelength $\lambda = 0.65\mu$ and 0.38 for $\lambda = 0.55\mu$, the following among other results have been obtained.

Emissivities of Metals and Oxides with Micropyrometer.

Metals.	Cu.	Ag.	Au.	Pd.	Pt.	Ir.	Rh.	Ni.	Co.	Fe.	Mn.	Ti.
$e_\lambda = 0.65\mu$ solid	.10	.04	.14	.33	.33	.30	.29	.36	.36	.37	.59	.63
$e_\lambda = 0.65\mu$ liquid	.15	.07	.22	.37	.38	....	.30	.37	.37	.37	.59	.65
$e_\lambda = 0.55\mu$ solid	.38	.35	.38	.38	.38	....	....	.44	....	....	....	.75
$e_\lambda = 0.55\mu$ liquid	.36	.35	.38	....	....	....	....	.46	....	....	....	.75

	Zr.	Th.	Y.	Er.	Be.	Cb.	V.	Cr.	Mo.	W.	U.	
$e_\lambda = 0.65\mu$ solid	.32	.36	.35	.55	.61	.49	.35	.39	.43	.39	.54	....
$e_\lambda = 0.65\mu$ liquid	.30	.40	.35	.38	.61	.40	.32	.39	.40	....	.34	....
$e_\lambda = 0.55\mu$ solid	....	.36	....	....	.61	.61	.29	.53	....	....	.77	....
$e_\lambda = 0.55\mu$ liquid	....	....	....	.30	.81	....	....	....	....	....	....	....

Oxides Near F. P. s.	NiO.	Co_3O_4	Fe_3O_4	Mn_3O_4	TiO_2	ThO_2	Y_2O_3	BeO	CbO_x	V_2O_3	Cr_2O_3	U_3O_8
$e_\lambda = 0.65\mu$ solid	.89	.77	.63	....	.52	.57	.61	.37	.71	.69	.60	.30
$e_\lambda = 0.65\mu$ liquid	.68	.63	.53	.47	.51	.69	....	....	....	....	....	.31

For none of the metals examined was there a marked temperature coefficient in the range 900 to 2000° C. and for the most of them this coefficient is negligible, the emissivity usually agreeing also with the value at 20° C. For the white metals the emissivity usually shows very slight or no change at the melting point, but for gold, silver, copper, and uranium there is a marked discontinuity with red light. For palladium, there are anomalies in the behavior of the emissivity at the melting point; and for platinum the fact that there is a change in emissivity (for $\lambda = 0.65\mu$) on melting would influence the constancy of the Violle standard of light.

BUREAU OF STANDARDS, WASHINGTON.

ELECTROSTATIC MEASUREMENT OF SINGLE ELECTRODE POTENTIALS.[1]

BY A. W. EWELL.

DETERMINATIONS of the absolute values of single electrode potentials have often been sought from electrocapillary phenomena "dropping electrodes," endosmotic phenomena, etc. Considerable uncertainty attaches to the values obtained. Recent work by Billitzer gives values for electrode potential approximately 0.7 volt lower than the absolute values commonly given in tables.

[1] Abstract of a paper presented at the New York meeting of the Physical Society, October 31, 1914.

The writer has been seeking for several years to obtain absolute single electrode potentials by an electrostatic method. The final apparatus, in brief, consisted of a glass or quartz flask covered on the outside with metal which is connected to a Dolezalek electrometer. The flask contained the electrolyte and from the change of potential of the metal outside was determined the potential acquired by the electrolyte when the earthed electrode was dipped into the electrolyte.

Observations with zinc and zinc sulphate, copper and copper sulphate, silver and silver nitrate, with glass and quartz flasks, and silver and aluminum films on the outside, all gave values for the absolute single potentials which are consistent among themselves and are about 0.2 volt higher than Billitzer's values, *i. e.*, approximately 0.5 volt lower than the values found in recent tables. Errors from leakage and from conduction through quartz or glass were easily detected and corrected. Volta effects were proved to be zero by the substitution of mercury for the electrolyte.

WORCESTER POLYTECHNIC INSTITUTE.

SOME APPLICATIONS OF SIMPSON'S RULE IN INTEGRATING PERIODIC FUNCTIONS.[1]

BY FREDERICK BEDELL AND RALPH BOWN.

IF a quantity, x, varies as the time-integral of a second quantity, y (illustrated by the case of magnetic flux and electromotive force), that is, $x \propto \int y dt$, successive values of x may be determined from successive values of y, by plotting y as a curve and determining the areas between any initial ordinate and successive ordinates y_1, y_2, y_3, etc.

If these successive ordinates are taken at equal time-intervals and the curve for y is assumed to be made up of arcs of parabolas, the whole area is made up of a number of parabolic trapezettes, the areas of which can be accurately and easily determined by Simpson's Rule. This becomes most simple when y is periodically positive and negative, as in case of alternating electro-motive forces and fluxes, the negative half-waves being a repetition of the positive. In this case, applying Simpson's Rule, we have values of x in two series, thus: *First series*, $x_0 = 0$, $x_2 = y_0 + 4y_1 + y_2$, $x_4 = x_2 + y_2 + 4y_3 + y_4$, $x_6 = x_4 + y_4 + 4y_5 + y_6$, etc., to which must be added a constant C_1; *second series*, $x_1 = 0$, $x_3 = y_1 + 4y_2 + y_3$, $x_5 = x_3 + y_3 + 4y_4 + y_5$, $x_7 = x_5 + y_5 + 4y_6 + y_7$, etc., to which must be added a constant C_2. The constant to be added in each series is the mean value of two values of x, as found in that series, the time interval between which is one-half period. Thus, if values of y are given every 10° (where 360° is one period) and x is determined for this same interval, $C_1 = (y_0 + y_{18}) \div 2$, and $C_2 = (y_1 + y_{19}) \div 2$.

To test the method, y was assumed to be a sine function with values taken every 30° from a table; values of x determined by Simpson's Rule, as described above, were found accurate in this case to a twenty fifth of one per cent.

[1] Abstract of a paper presented at the New York meeting of the Physical Society, October 31, 1914.

As another test, values of y were taken every 10° from the equation

$$y = 1000 \sin x + 333 \sin 3x(x - 10°) + 100 \sin 5(x - 15°) + 50 \sin 13x.$$

Corresponding values of x, determined by the above rule, varied not more than a sixth of one per cent. from the values determined by tables. For curves even more irregular, it is believed the method will give results sufficiently accurate for most purposes and usually more accurate than can be otherwise obtained. For a fuller discussion, references and a comparison with other methods, see a paper about to be published by the authors entitled "Derivation of Wave-form of Flux from Wave-form of Electromotive Force," Electric Journal, 1915.

CORNELL UNIVERSITY.

THE ELECTRIC RESOLUTION OF THE SERIES LINES IN THE MERCURY SPECTRUM.[1]

BY GEORG WENDT AND REINHARD A. WETZEL.

THE transverse Stark effect was obtained in canal rays with electric fields measuring from 50,000 to 90,000 volts per centimeter.

In the sharp subordinate series of mercury triplets the following lines were investigated: λ2,925; 2,894; 2,752; 2,576; 2,464Å. The photograms obtained show no appreciable splitting or displacement of the lines with these fields under the dispersion at our disposal.

In the diffuse subordinate series of mercury triplets we investigated the following: λ3,132; 3,024; 2,967; 2,803; 2,699; 2,652; 2,534; 2,482Å. With the exception of λ2,967 all show splitting and displacements due to the action of the electric field. Quantitatively the effect is not the same upon each member of the triplet. It is largest upon the first, smaller upon the second, and smallest upon the third component of the triplet. The effect also increases rapidly with the increasing term numbers of the series.

Results.—(1) A confirmation of Stark's series laws for the electric effect—viz., there is a difference between sharp and diffuse subordinate series, there is an increase of the effect with increase of term number; (2) A confirmation of the fact that for the different elements the nature and magnitude of the electric effect upon series lines of the same term number is not a function of their atomic weights but first and foremost a characteristic of the chemical element (its valence electrons). The photograms show this fact even more beautifully than those obtained by Stark and Kirschbaum.

The above investigation was made at the Physical Institute of the Technical High School at Aachen, Germany, during July, 1914. Thanks are due Prof. Stark for the privileges of the laboratory. His rich experience and thoughtful suggestion also served us during the entire work.

[1] Abstract of a paper presented at the New York meeting of the Physical Society, October 31, 1914.

THE TRANSVERSE STARK EFFECT UPON ALUMINUM DOUBLETS.[1]

BY REINHARD A. WETZEL.

Sharp Subordinate Series.—Electric fields of from 50,000 to 90,000 volts per centimeter show no appreciable effect upon the doublet λ2,660 − 2,652Å. under the dispersion used.

Diffuse Subordinate Series.—Under the above conditions the following doublets were investigated:

$$\lambda 3{,}093 - 3{,}082; \quad 2{,}575 - 2{,}568; \quad 2{,}373 - 2{,}367\text{Å}.$$

Upon the first two pairs no appreciable effect is noticeable on the photographic plates. Of the last pair the line λ2,373Å. shows a small displacement toward the red, both in the vectors oscillating parallel and in those oscillating perpendicular to the field.

Acknowledgement of indebtedness is due to Prof. Stark for suggesting the research and the opportunities that he so generously placed at our disposal in his laboratory at Aachen.

THE TOTAL EMISSIVITY OF PLATINUM AND THE RELATION BETWEEN TOTAL EMISSIVITY AND RESISTIVITY.[1]

BY PAUL D. FOOTE.

THE theory of radiation from metals developed by Aschkinass has been extended and the following general equation has been derived for the total emissivity of a metal:

$$E = 0.5736\sqrt{rT} - 0.1769rT,$$

where E is the total emissivity at the absolute temperature T and r the volume resistivity of the metal at this temperature. Experimental observations upon platinum obtained by the use of radiation pyrometers confirmed the above theoretical relation. A table of corrections is given for converting temperatures observed with a radiation pyrometer sighted upon platinum, to true temperatures. The following table represents the total emissivity of pure platinum as a function of the temperature.

°C.....	0	200	400	600	800	1000	1200	1400	1700
E.....	.030	.051	.070	.089	.108	.124	.140	.155	.175

BUREAU OF STANDARDS, WASHINGTON.

AN ACHROMATOSCOPE.[1]

BY S. R. WILLIAMS.

AN optical device for attaching to any spectroscope has been devised whereby the channeled spectra of light reflected from two thin films may be compared. When the thin films are wedge shaped the thickness of one film may be varied until the optical path in the two films are the same for any

[1] Abstract of a paper presented at the New York meeting of the Physical Society, October 31, 1914.

given wave-length. If complete achromatization occurs the interference bands will be in coincidence throughout the spectrum when the order of interference, N, for a certain wave-length in one film is the same for the same wave-length in the other film. In other words, we have the relation holding that,

$$\frac{\partial N_1}{-\partial \lambda} = \frac{\partial N_2}{-\partial \lambda}.$$

The thin films may be easily prepared and instead of laboriously measuring the indices of refraction in order to determine the degree of achromatization of crown and flint glasses, thin sections of the two kinds of glasses are slipped into position and on adjusting the interference bands in the field of view of the spectroscope, the degree of achromatization may be obtained by inspection.

When sunlight is used as a source of light the Fraunhofer lines are simultaneously produced with the interference bands and in photographing afford a convenient scale of wave-lengths.

PHYSICAL LABORATORY, OBERLIN COLLEGE,
July, 1914.

NEW BOOKS.

Die Lichtelektrischen Erscheinungen. By R. POHL AND P. PRINGSHEIM. Braunschweig: Vieweg and Sohn, 1914. Pp. 1 + 114. Price Mk 3.

This monograph, on photoelectric phenomena, deals especially with the subject as it has been developed through the researches of the authors, and is therefore more limited in its scope than the recently published monographs by Ries, and Stanley Allen.

Special prominence is given to those phases of the subject dealing with the selective and normal photo-effects of metals.

The work includes chapters on the photo-effect of non-metallically conducting bodies, the effect of surface layers on the photo-effect, and the ionization of gases by light. The closing chapter gives a resumé of the work done by Lindemann, Debyje Sommerfeld and others on the interpretation of photoelectric action in the light of the quantum theory.

The bibliography which is appended is most exhaustive and is brought down to September, 1913. It is regrettable that the work was written before the publication of papers by Wiedemann and Hallwachs, Friedenhagen, Küstner and Hughes on the part played by occluded gases in photoelectric phenomena.

J. C. M.

La Telegraphie et La Telephonie Simultanees et La Telephonie Multiple. By K. BERGER. Paris: Gauthier-Villars, 1913. Pp. 1 + 134.

The book contains three chapters: (1) Telephony over telegraph lines; (2) Telegraphy over telephone lines; and (3) The simultaneous transmission of several telephonic messages over the same line. The treatment is rather technical in character, but the physicist will find much of interest, especially the historical data and the clear presentation of the underlying scientific principles with which each chapter is introduced. The book is a French translation by Le Normand of the German work.

K. E. G.

Taschenbuch für Mathematiker und Physiker. By FELIX AUERBACH AND RUDOLF ROTHE. Leipzig: Druck, 1913. Pp. x + 463. Price, Mk. 6.

Into this small book is compressed a large amount of valuable information, both in mathematics and physics. Beginning with an account of the life of Friedrich Kohlrausch, there follow a number of numerical tables of various functions, and a very compendious presentation of various departments of mathematics including a short account of integral equations. In physics there

are also useful tables, with much general information. Particularly interesting is an account of the quantum theory by Sommerfeld. A list of recent books is included.

A. G. W.

Collected Papers in Physics and Engineering. By JAMES THOMSON. Cambridge: University Press, 1912. Pp. civ + 484.

This volume adds to the debt of gratitude which students of physics owe to Sir Joseph Larmor for the editorial labor and skill he has devoted to the collection, in convenient and accessible form, of the scientific papers and correspondence of the great physicists of the Victorian era. In the present instance he has had the assistance of James Thomson, M.A., the son of Professor Thomson; and the very interesting Biographical Memoir, with which the volume opens, "has been constructed largely out of narratives and recollections obtained by his daughter Mary Hancock Thomson."

James Thomson was two years older than his brother William, and the two were from childhood devotedly attached to each other. It is inevitable that this close association with his more brilliant junior must have had a considerable effect upon his own scientific work; yet these papers show very clearly that James possessed a mind of great independence and originality, and the correspondence between the brothers (a few examples of which are contained in this volume) make it plain that the influence and help were not all on one side. The difference in the characters of the two men are distinctly shown in their published work. After a perusal of the present volume, one is entirely convinced of the accuracy of the statement in the biographical sketch that, as boys and throughout their lives, "James was the more careful and exact, and William the more quick and ready."

James Thomson was, by profession, an engineer and was for many years professor of engineering, first in Queen's College, Belfast, and afterward in the University of Glasgow. He made many investigations and inventions in the subject of hydraulics, accounts of which are contained in the first section of the present volume. He invented a turbine water-wheel, a centrifugal pump and a jet pump which were much used in their time; and he made great improvements in the measurement of running water by weir-boards, especially by his introduction of the triangular notch. One short paper in this section contains his explanation of the "tears of strong wine" which is familiar to all readers of Maxwell's Theory of Heat.

The second division of papers on "Congelation and Liquefaction" begins with the celebrated calculation, from Carnot's theory, of the lowering of the freezing point of water by pressure. As was still customary at the time (1849), notwithstanding the previous work of Mayer, Joule and Helmholtz, the argument assumes, like that of Carnot himself, the perfect conservation of heat. As is well known, the calculation was numerically verified soon after by Lord Kelvin; it is quite plain from his language that the fact that "an entirely novel physical phenomenon was *predicted* in anticipation of any

direct experiment" had a great effect upon his mind, and must have contributed to his reluctance to accept Joule's theory until he had, with much difficulty, reconciled it with Carnot's.

The remaining papers of this section (together with some correspondence with Faraday which is included) is mainly concerned with regelation and the plasticity of ice in glaciers; there was much difference of opinion on these subjects, but Thomson's views were well considered and sound, and he maintained them with courage and tenacity even against the great authority of Faraday.

During his residence in Belfast, Thomson was a colleague of Andrews and was deeply interested in his experiments upon the critical state and the continuity of the liquid and gaseous states. His contributions to this subject form the third section of papers. As is well known, he first suggested some of the ideas which were afterward worked out more completely by van der Waals. He also investigated the triple-point and made the first thermodynamic model in three dimensions.

The fourth section on "Dynamics and Elasticity" is perhaps of less general interest than the preceding ones. The paper on "Inertia, Chronometry, Absolute Motion" however might well arrest attention as a fore-runner of the modern doctrine of relativity—especially the statement on p. 380 of the difficulty of defining simultaneity.

The book concludes with three papers on geological subjects, some miscellaneous papers, and an appendix containing three papers of general, rather than scientific, interest.

H. A. B.

Molecular Physics. By JAMES ARNOLD CROWTHER, M.A. Philadelphia: P. Blakiston's Son & Co., 1914. Pp. viii + 167. Price, $1.25.

This little book has been prepared to meet the need of those who desire to know what has been learned through recent researches of the constitution and properties of atoms and molecules.

It contains chapters which deal with the physics of the electron, the properties of alpha rays, positive ray analysis, as developed by Sir J. J. Thomson, the chemistry of the atom in the light of the electron theory, the Zeeman effect, spectral series, the origin of spectra, the kinetic theory of heat, the electronic theory of thermal and electrical conduction, radioactivity and radioactive transformations. It also contains three appendices of mathematical notes illustrating the matter of the text and closes with a table of atomic data, and a bibliography. The book has been written with care and will prove extremely useful.

J. C. M.

La Technique de La Radiotelegraphie. By DR. ING. H. REIN. Paris: Gauthier-Villars, 1913. Pp. x + 257.

This book is a translation into French of the second edition of Rein's Radio-

telegraphisches Praktikum. It was originally written as a laboratory guide for students of wireless telegraphy, but in its present form it contains much which would not be found in a mere laboratory manual. After a short introduction, discussing the characteristic features of various systems of wireless telegraphy the main part of the book is devoted to a description of high frequency instruments and the best methods for their calibration. Measurements of capacities, self and mutual inductances, wave-length and damping under such conditions as are found in actual practice are given in detail and in each case a large number of different methods is given. Then follows a chapter on generators and receivers of various types. The book closes with a discussion of the guiding principles for the erection of wireless stations.

The illustrations are practically restricted to apparatus used in Germany and the bibliography contains only a few references to publications in any other but the German language. The treatment of the subject is excellent and the book should be found in every laboratory of wireless telegraphy. We are indebted to the translator, G. Viard, to have made this book available to students who are unable to read it in the original.

K. E. G.

Practical Physics. By N. H. BLACK AND H. N. DAVIS. New York: The Macmillan Company, 1913. Pp. ix + 487. Price, $1.25 net.

This is an elementary physics text-book which follows for the most part established lines. It is a somewhat longer treatise than other elementary text-books due largely to more descriptions of commercial devices.

E. S. B.

Second Course in Algebra. By WILLIAM BENJAMIN FITE, New York: D. C. Heath and Company, 1914. Pp. v + 247.

This is an attractive and clearly written text for students who have had a year of algebra.

F. B.

Elektrische Spektralanalyse chemischer Atome. By DR. J. STARK. Leipzig: S. Hirzel, 1914. Pp. viii + 138. Price, Mk. 5.

This monograph contains an account of the phenomenon of electric resolution of spectral lines recently discovered by Stark, and includes a detailed description of the different experimental methods of observing the effect.

The chapter dealing with the dependence on field intensity of the strength and the distance apart of the electrically resolved constituents of a line as well as that on the analysis of lines of the same series and of different elements is specially well prepared.

The monograph contains a chapter on phenomena allied to the Stark effect, and also one which deals entirely with theoretical considerations regarding it. The bibliography appended is excellent.

J. C. M.

Experimental Studies in Electricity and Magnetism. By FRANCIS E. NIPHER. Philadelphia: P. Blakiston's Son & Co., 1914. Pp. 1 + 73. Price, $1.25.

This book contains in connected form the results of Professor Nipher's researches, which have been published from time to time since 1910 by the Academy of Sciences of St. Louis. The author undertakes to obtain evidence from the ordinary electric discharge in air which can be used to decide between the claims of the "one-fluid" and the "two-fluid" theories of electricity. His observations are extremely curious and interesting. They well deserve the consideration of anyone who is concerned with the phenomena of the electric discharge. The author concludes that they can be explained on the "one-fluid" theory. He agrees with Aepinus that this theory necessitates the mutual repulsion of material particles, and believes that he observes this in the explosion of a lead wire into which a discharge passes from a neighboring positive terminal. The creeping of a wire in the direction opposite to that of the corpuscular (*i. e.*, negative) discharge passing along it is remarkable.

A short section at the end of the book deals with the author's observations of the connection between magnetic storms and certain conditions of weather.

W. F. M.

Gas Analysis. By L. M. DENNIS. New York: The Macmillan Company, 1913. Pp. xvi + 434. Price, $2.10.

This book is written for technical chemists and contains descriptions of apparatus and methods for rapid gas analysis. Elementary physical laws are briefly mentioned at the proper places. Some contact with the physicist is made in such chapters as: "The determination of the specific gravity of a gas; the purification of mercury; the determination of the heating value of fuel; the examination of atmospheric air." K. E. G.

Geometry of Four Dimensions. By HENRY PARKER MANNING, New York: The Macmillan Company, 1914. Pp. ix + 348. Price, $2.00.

Aristotle made the statement that "beyond these (three dimensions) there is no other magnitude because these three are all." After an interesting historical introduction, reviewing the development of the geometry of more than three dimensions from its negation by Aristotle until its recognition as a branch of modern mathematics, the author discusses the subject in chapters as follows: The Foundations of Four-Dimensional Geometry; Perpendicularity and Simple Angles; Angles of Two Planes and Angles of Higher Order; Symmetry, Order, and Motion; Hyperpyramids, Hypercones, and the Hypersphere; Euclidean Geometry; Figures with Parallel Elements; Measurement of Volume and Hypervolume in Hyperspace; The Regular Polyhedroids.

F. B.

Mathematical Theory of Heat Conduction. By L. R. INGERSOLL AND O. J. ZOBEL. Boston: Ginn and Company, 1913. Pp. vi + 171. Price, $1.60.

The authors have succeeded in producing a very attractive short treatise

on this very important subject to the physicist. By a judicious selection of problems they have managed to include the most important methods and at the same time to treat a great variety of practical questions of interest to the engineer or the geologist. The figures are clear and luminous, and the graphical representation of the approximations by Fourier's series is to be commended. An idea of the physical good sense displayed in the choice of subject-matter may be obtained from the following, chosen at random; the theory of "cold waves," flow in engine-cylinder walls, the fireproof wall, annealing of castings, the formation of ice, all worked out with numerical values.

The mathematician will regret that in the treatment of Fourier's theorem, page 60, Fourier's error in giving the wrong order of integration is perpetuated, but this will not worry the physicist much, and to him the book is unhesitatingly to be commended. A. G. W.

College Physiography. By RALPH STOCKMAN TARR. Published under the Editorial Direction of Lawrence Martin. New York: The Macmillan Company, 1914. Pp. xxii + 837. Price, $3.50. (*Received.*)

The Electrical Conductivity and Ionization Constants of Organic Compounds. By HEYWARD SCUDDER. New York: D. Van Nostrand Company, 1914. Pp. 1 + 568. Price $3.00.

Besides an explanatory introduction, lists of abbreviations, etc., this book contains three tables. The first consisting of 280 pages, is an alphabetical list of all the organic compounds whose electro-chemical properties have been hitherto studied; under each compound are given values of its specific conductivity and ionization constant as determined by different observers at various temperatures and under a variety of other conditions. In each case cross-references (by number) are given to the third table, or "Author List," which the author believes to be an almost or quite complete bibliography of the subject from 1889 to 1910. The second table is an index of the chemical formulæ of the compounds mentioned, and there is at the end of the book a Subject Index giving references to the bibliography.

The work appears to be done in a very thorough and painstaking manner and must have involved great labor. It will doubtless prove of value to all investigators whose work involves the electro-chemical properties of organic compounds. H. A. B.

Physics of the Household. By C. J. LYNDE. New York: The Macmillan Company, 1914. Pp. xi + 313. Price, $1.25.

"This is an elementary text-book of physics, written for students of household science." It is so distinctly practical in its aim that the treatment of dynamics is reserved for the last chapter and occupies fourteen pages. There is practically no discussion of the theories of physics. The laws of physics are stated concisely and are illustrated by examples of their application in common instruments used about the house, ranging in intricacy of construc-

tion from the tack lifter to the vacuum cleaner. The book is one which may well serve the purpose for which it is designed but it would not do for use in a course of instruction in which physics is taught for its scientific content or as a medium for the inculcation of scientific method.

On page 59 Henry's law is ascribed to "The American physicist Henry." The Henry of the law was William Henry of Manchester, England. The American physicist Joseph Henry was a younger man by twenty-three years than the other, and could not very well, without extraordinary precocity, have announced a discovery in 1803, when he was six years old.

W. F. M.

Mechanics and Heat. By W. B. ANDERSON. New York: McGraw-Hill Book Company, 1914. Pp. xi + 349. Price, $2.00 net.

Professor Anderson has made the interesting attempt of writing a college text on mechanics and heat in which the mathematics is reduced to an amount not much greater than that found in the more advanced high school texts. On the other hand he has placed more emphasis on practical applications and elementary methods of measurement than is usual in college texts.

The book is evidently intended for the instruction of students in agriculture and doubtless serves its purpose for this type of students. The mathematical structure is, however, too light to serve as a foundation for a severe training in engineering. The treatment is very clear and interesting and the illustrations excellent.

K. E. G.

Allgemeine Ergebnisse und Probleme der Naturwissenschaft. By DR. BERNHARD BAVINK. Leipzig: S. Hirzel, 1914. Pp. xiii + 314. Price, Mk. 7.

This volume aims at giving a philosophical treatment in a condensed form of some of the more general results and problems of present day science. In the first section the subjects presented include the atomic theory of matter, the equivalence of different forms of energy, the kinetic theory of heat, the electromagnetic theory of light, the electromagnetic nature of mass, the emission and absorption of light, and the principle of relativity. The second section includes a discussion of the bearing of the law of entropy on the problem of the future of the world, and a detailed account of such matters as the configuration and motion of fixed star systems, world history, recent advances in our knowledge of meteorological phenomena, and problems relating to cosmogony generally. The third section is devoted to the problem of life, and deals with the physical and chemical basis of life, the simple living cell, vitalism, the origin of life, the principle of causality in biology, and problems arising from a study of multicellular organisms. In the concluding section the subjects dealt with are the theories of evolution and mutation, and problems dealing with the origin of man and his position in the Universe.

The book contains much that is of great interest to those wishing to ascertain the philosophical bearing of recent contributions to knowledge in different branches of science.

J. C. M.

Report on Radiation and the Quantum-Theory. By J. H. JEANS. London: The Electrician Printing and Publishing Co., Ltd., 1914. Pp. iv + 90. Price 6s.

In this brief but comprehensive report, Professor Jeans discusses the modern problem of radiation and its proposed solution by the quantum theory. For some time past Jeans has been reluctant to concede that the general principle of equipartition of energy, which can be demonstrated for dynamical systems, does not apply to the ether as well as to matter in systems which are in true equilibrium. But in this report he frankly accepts the necessity of assuming that the relations of the ether to matter are not subject to dynamical principles, and admits that some laws other than the Newtonian laws must determine the phenomena of radiation. He shows that the Newtonian laws lead to the Rayleigh-Jeans formula, which is inconsistent with the observed facts, and that the hypothesis of the energy quantum leads to Planck's formula. He then gives an exposition of Nicholson's theory of line-spectra, and an account of Bohr's theory of the atom and its relations to the emission of radiation. He also discusses the photoelectric effect and the recent work of Debye and others on the heat capacities of solids and shows that the quantum theory will explain the facts observed. In a final chapter on the physical basis of the quantum theory he discusses most acutely the course which speculation must take in the endeavor to construct a new mechanics which shall be comprehensive enough to contain the laws of radiation. He points out that Einstein's light-quanta are inconsistent with the undulatory theory of light, but gives no definite positive conception of what the quantum is, or of the way in which its theory can be developed. In fact nowhere, except in Planck's preface to his Theory of Radiation, is there given a more striking statement of the necessity for a new theory of the physical universe and of the immense distance which we seem to be from realizing such a theory.

The report is written with all the author's well known brilliancy and clearness, and will take rank with similar reports by other English masters as a physical classic.

W. F. M.

Elements of General Science. By O. W. CALDWELL AND W. L. EIKENBERRY. New York: Ginn and Co., 1914. Pp. xiv + 308. Price, $1.00.

This book represents a pedagogical effort to properly direct the science instruction in the first year of high school work. It emphasizes in particular the physics and chemistry of air and water. The topics discussed are grouped under five headings, the air, water and its uses, work and energy, the earth's crust, and life upon the earth. The treatment throughout is logical and connected, and the principles developed are illustrated with numerous examples drawn from nature.

The chapters dealing with weather, the relation of air to food production, the distribution of disease germs, the climatic influence of bodies of water, water supplies and sewage disposal, soil physics, plant physics, the world's

food supply, nutrition, reproduction and the struggle for existence are particularly well written. A book of this character should be in the hands of every teacher of elementary science. J. C. M.

Photo-Electricity. By ARTHUR LLEWELYN HUGHES. Cambridge Press, 1914. Pp. i–viii + 1–142.

Within a single year three books have appeared on photo-electricity and all of them by men who have been actively engaged in pushing ahead the bounds of knowledge in this field. Nevertheless each book shows marked individuality and no two of them are at all alike. Allen's is the most compendious (220 pages) and Pohl and Pringsheim's the most special, dealing largely with work done at the Physical Institute in Berlin, while Hughes' book is remarkable for its combination of thoroughness with conciseness, for its scholarly fairness to all observers, and for the skill and insight with which the varied facts of photo-electricity are given a theoretical significance. Indeed it is by forsaking entirely the historical method and aiming immediately at the statement and explanation of photo-electric facts as they now stand that Hughes has succeeded so well in compressing a very complete treatment of a large field into 140 pages. In many respects the book is noteworthy. R. A. M.

Mathematics, from the Points of View of the Mathematician and of the Physicist. By E. W. HOBSON. Cambridge: University Press, 1914. Pp. 1 + 24. Price, 1s.

In this address, delivered originally before the Mathematical and Physical Society of University College, London, Professor Hobson has pointed out, with great clearness and entire impartiality, the reasons which underly the different attitudes of mathematicians and of physicists toward the study of mathematics. The subject is illuminated by the author's great learning and enlivened by characteristic touches of humor and by accounts of significant misunderstandings between some of the great physicists and mathematicians of the past. A student of either science can scarcely fail to derive both pleasure and profit from a perusal of the lecture. H. A. B.

Die Lichtbrechung in Gasen als physikalisches und chemisches Problem. By DR. ST. LORIA. Braunschweig: Vieweg und Sohn, 1914. Pp. vi + 92. Price, Mk. 3.

This monograph which is one of the Vieweg collection contains a concise summary of all the work which has been done on the refractivity and dispersion of gases. It contains chapters on the electromagnetic theory of dispersion, the methods of determining the refractivity of gases, the dependence of refractive power of gases on pressure and temperature, and the refractivity and dispersion of compound gases and of gaseous mixtures. The references inserted as footnotes are most complete, and altogether the work is one of the best prepared of those of the series which have been brought to the attention of the reviewer. J. C. M.

ERRATA AND ADDENDA.

Volume III. The index (June, 1914) failed to include reference to the article by Frances G. Wick entitled "A Spectrophotometric Study of the Absorption, Fluorescence, and Surface Color of Magnesium Platinum Cyanide," which was published in the May, 1914, issue, p. 382.

Page 177, Vol. IV. To the paper by David L. Webster entitled "The Effect of Pressure on the Absorption of Light by Bromine and Chlorine, and its Theoretical Significance," reference is added, at the request of the author, to the work of Prof. C. Schaefer, one of the first to investigate the deviations from Beer's Law in Gases, published in Annalen der Physik, 16, 1, pp. 93–105, January 26, 1905.

INDEX TO VOL. IV, SERIES II.

A.

Absorption of Light, The Effect of Pressure on the, by Bromine and Chlorine, and its Theoretical Significance, *David L. Webster*, 177, 561.

Absorption Spectrum, Note on the Relation between the Emission Spectrum of a Compound and its, in Solution, *Albert K. Chapman*, 28

Achromatoscope, An, *S. R. Williams*, 550.

Acoustic Shadow, Phase Relations in the, of a Rigid Sphere; Phase Difference at the Ears, *G. W. Stewart*, 252.

Adams, Elliot Q., The Distribution of Thermal Energy, 331.

Addenda, 561.

Alpha-Ray Activities, The Relation between, and Ranges in the Actinium Series with Notes on the Period and Range of Radioactinium, *Herbert N. McCoy and Edwin D. Leman*, 409.

American Physical Society.
Abstracts, 71, 287, 396, 545.
Minutes, 344.

Avogadro's Constant N, A Determination of, from Measurements of the Brownian Movements of Small Oil Drops Suspended in Air, *Harvey Fletcher*, 400.

B.

Bedell, Frederick, Some Applications of Simpson's Rule in Integrating Periodic Functions, 548.

Bown, Ralph, Some Applications of Simpson's Rule in Integrating Periodic Functions, 548.

Brady, Edw. J., A New Design of Flicker Photometer for Laboratory Colored Light Photometry, 222.

Bromine, The Effect of Pressure on the Absoprtion of Light by, and Chlorine, and its Theoretical Significance, *David L. Webster*, 177.

Brown, F. C., The Crystal Forms of Metallic Selenium and Some of their Physical Properties, 85.

Wave-Length-Sensibility Curves for Light Sensitive Selenium and their Significance, 48.

Wave-Length-Sensibility Curves of Certain Crustals of Metallic Selenium; and a Partial Explanation of the Complexity of Light-Action in Selenium Cells, 507.

Brownian Movements, A determination of Arogadro's Constant N, from Measurements of the, of Small Oil Drops suspended in Air, *Harvey Fletcher*, 440.

Buckingham, E., On Physically Similar Systems; Illustrations of the Use of Dimensional Equations, 345.

Buckley, O. E., The Hall Effect and Allied Phenomena in Silicon, 482.

Burgess, G. K., The Emissivity of Metals and Oxides, II: Measurements with the Micropyrometer, 546.

C.

Cathode Particles, on the Passage of, through Gases at Low Pressure, *L. W. McKeehan*, 140.

Chapman, Albert K., Note on the Relation between the Emission Spectrum of a Compound and its Absorption Spectrum in Solution, 28.

Chlorine, The Effect of Pressure on the Absorption of Light by Bromine and, and its Theoretical Significance, *David L. Webster*, 177.

Child, C. D., The Spectrum from Mercury Vapor in an Electric Field, 387.

Coblentz, W. W., A Comparison of Stellar Radiometers and Radiometric Measurements on Stars, 545.

Color Analyses of Two Component Mixtures, *L. A. Jones*, 454.

Contact Potentials, A Study of, and Photoelectric Properties of Metals in Vacuo: and the Mutual Relation between these Phenomena, *Albert E. Hennings*, 228.

Coulson, John, The Reproduction and

Measurement of Very Short Intervals of Time, 40.

D.

Davey, Laura G., The Mean Depth of Formation of X-Rays in a Platinum Target, 217.

Davey, Wheeler P., The Factors which Determine the Quantity of Roentgen Radiation given off by an X-Ray Tube, 208.

Dieterich, E. O., The Influence of Annealing on the Characteristics of Light Sensitive Selenium, 467.

Diffraction, Some Effects of, on Brightness Measurements made with the Holborn-Kurlbaum Optical Pyrometer, *A. G. Worthing and W. E. Forsythe*, 163.

Dimensional Equations, Illustrations of the Use of, *E. Buckingham*, 345.

Dioptric Formulæ for Cylindrical Lenses Combined at Oblique Axes, *Charles Sheard*, 274.

Discharge Phenomena, Some Brush, Produced by Continuous Potentials, *Stanley P. Farwell*, 31.

Douglas, J. F. H., The Approximate Determination of the Resistance of an Irregular Conductor, 391.

Dushman, Saul, Determination of *e/m* from Measurements of Thermionic Currents, 121.

E.

"*e*," Determination of the Value of, by Millikan's Method, Using Solid Spheres, *John Yiubong Lee*, 420.

Earhart, Robert F., The Effect of a Longitudinal Magnetic Field on Spark Potentials, 135.

Electric Field, The Spectrum from Mercury Vapor in an, *C. D. Child*, 387.

Electric Resolution, The, of the Series Lines in the Mercury Spectrum, *George Wendt and Reinhard A. Wetzel*, 549.

Electrode Potentials, Electrostatic Measurement of Single, *A. W. Ewell*, 547.

Electron Atmosphere, Note on Evidence for, *F. F. Householder*, 47.

Electrostatic Measurement of Single Electrode Potentials, *A. W. Ewell*, 547.

Emission Spectrum, Note on the Relation between the, of a Compound and its Absorption Spectrum in Solution, *Albert K. Chapman*, 28.

Emissivity, The, of Metals and Oxides, II; Measurements with the Micropyrometer, *G. K. Burgess*, 546.

Emissivity, The Total, of Platinum and the Relation between Total Emissivity and Resistivity, *Paul D. Foote*, 550.

Errata, 561.

Ewell, A. W., Electrostatic Measurement of Single Electrode Potentials, 547.

F.

Farwell, Stanley P., Some Brush Discharge Phenomena Produced by Continuous Potentials, 31.

Ferromagnetic Substances, The Villari Critical Point in, *S. R. Williams*, 288.

Fletcher, Harvey, A Determination of Avogadro's Constant N from Measurements of the Brownian Movements of Small Oil Drops Suspended in Air, 440.

Flicker Photometer, A New Design of, for Laboratory Colored Light Photometry, *Herbert E. Ives and Edw. J. Brady*, 222.

Foote, Paul D., The Total Emissivity of Platinum and the Relation between Total Emissivity and Resistivity, 550.

Forsythe, W. E., High Temperature Measurements with the Stefan-Boltzman Law, 62.

Some Effects of Diffraction on Brightness Measurements made with the Holborn-Kurlbaum Optical Pyrometer, 163.

G.

Goddard, Robert H., On Pondermotive Force upon a Dielectric which Carries a Displacement Current in a Magnetic Field, 99.

Gowdy, R. C., On the Absorption of Hydrogen by Sodium Potassium Electrodes, 401.

Granthan, G. E., The Time Factor in Selenium Resistance, 259.

Grondahl, L. O., The Thermoelectricity and Magnetostriction of Heusler Alloys, 325.

H.

"*h*," A Direct Determination of, *R. A. Millikan*, 73.

h, Note on the Direct Determination of, *O. W. Richardson*, 522.

Hall Effect, The, and Allied Phenomena in Silicon, *O. E. Buckley*, 482.

Hartsough, Ralph C., Characteristics of Contact Rectification with a Silicon Carbon Contact, 306.

Heat of Solids, The Specific, and the Principle of Similitude, *Richard Chace Tolman*, 145.

Heising, R. A., Magnetic Resistance Change of Pure Iron, 315.

Hennings, Albert E., On the Nature of the Volta Effect: A Rejoinder, 247.

A Study of Contact Potentials and Photo-electric Properties of Metals in Vacuo: and the Mutual Relation between these Phenomena, 228.

Heusler Alloys, The Thermoelectricity and Magnetostriction of, *L. O. Grondahl*, 325.

High Temperature Measurements with the Stefan-Boltzman Law, *C. E. Mendenhall and W. E. Forsythe*, 62.

High Vacua, Experiments on the Production and Measurement of, *J. W. Woodrow*, 491.

Householder, F. F., Note on Evidence for Electron Atmosphere, 47.

Howes, H. L., The Luminescence of Kunzite, 18.

Hydrogen, On the Absorption of, by Sodium Potassium Electrodes, *R. C. Gowdy*, 401.

I.

Intervals of Time, The Reproduction and Measurement of Very Short, *John Coulson*, 40.

Irregular Conductor, The Approximate Determination of the Resistance of an, *J. F. H. Douglas*, 391.

Ives, Herbert E., A New Design of Flicker Photometer for Laboratory Colored Light Photometry, 222.

J.

Jones, L. A., Color Analyses of Two Component Mixtures, 454.

Joule Magnetostrictive Effects, A Comparison of the Longitudinal and Transverse, in the same Specimens of Steel and Nickel, *S. R. Williams*, 498.

K.

Kennard, E. H., Rate of Decay of Phosphorescence at Low Temperatures, 278.

Kraus, Charles A., The Temperature Coefficient of Resistance of Metals at Constant Volume and its Bearing on the Theory of Metallic Conduction, 159.

Kunzite, The Luminescence of, *E. L. Nichols and H. L. Howes*, 18.

L.

Langmuir, Irving, The Vapor Pressure of the Metals Platinum and Molybdenum, 377.

Lee, John Yiubong, Determination of the Value of "*e*," by Millikan's Method, Using Solid Spheres, 420.

Leman, Edwin D., The Relation between Alpha-Ray Activities and Ranges in the Actinium Series with Notes on the Period and Range of Radioactinium, 409.

Lewis, Gilbert N., The Distribution of Thermal Energy, 331.

Luckiesh, M., On the Growth and Decay of Color Sensations in Flicker Photometry, 1.

Luminescence, The, of Kunzite, *E. L. Nichols and H. L. Howes*, 18.

M.

Mackay, C. M. J., The Vapor Pressure of the Metals Platinum and Molybe denum, 377.

McCoy, Herbert N., The Relation between Alpha-Ray Activities and Ranges in the Actinium Series with Notes on the Period and Range of Radioactinium, 409.

McKeehan, L. W., On the Passage of Cathod-Particles through Gases as Low Pressure, 140.

Magie, William Francis, The Specific Heats of Mixtures of Alcohol and Water and of Solutions of Non-electrolytes in these Mixtures, 287.

Magnesium Platinum Cyanide, A Spectrophotometric Study of the Absorption, Fluorescence, and Surface Color of, *Frances G. Wick*, 561.

Magnetic Field, The Effect of a Longitudinal, on Spark Potentials, *Robert F. Earhart*, 135.

Magnetic Qualities, A Study of the, of Stressed Iron and Steel, *C. M. Smith and Geo. W. Sherman, Jr.*, 267.

Magnetic Resistance Change of Pure Iron, *R. A. Heising*, 315.

Mendenhall, C. E., High Temperature Measurements with the Stefan-Boltzman Law, 62.

Mercury Vapor, The Spectrum from, in an Electric Field, *C. D. Child*, 387.

Micropyrometer, Measurements with the, *G. K. Burgess and R. G. Waltenberg*, 546.

Millikan, R. A., A Direct Determination of "*h*," 73.

Millikan, R. A., The Effect of Residual Gases on Contact E.M.F.'s and Photo-Currents, 73.

Molybdenum, The Vapor Pressure of the Metals Platinum and, *Irving Langmuir and C. M. J. Mackay*, 377.

N.

New Books, 76, 154, 397, 552.

Nichols, E. L., The Luminescence of Kunzite, 18.

O.

Optical Pyrometer, Some Effects of Diffraction on Brightness Measurements made with the Holborn-Kurlbaum, *A. G. Worthing and W. E. Forsythe*, 163.

P.

Periodic Functions, Some Applications of Simpson's Rule in Integrating, *Frederick Bedell and Ralph Bown*, 548.

Pfund, A. H., A Contrast Equality Photometer, 477.

Phosphorescence, Rate of Decay of, at Low Temperatures, *E. H. Kennard*, 278.

Photo-electric Properties, A Study of Contact Potentials and of Metals in Vacuo: and the Mutual Relation between these Phenomena, *Albert E. Hennings*, 228.

Photo-Electrons, On the Asymmetric Emission of, from Thin Films of Platinum, I, *Otto Stuhlmann, Jr.*, 195.

Photometer, A Contrast Equality, *A. H. Pfund*, 477.

Photometer, Measurements with a Moving Lamp, *C. C. Trowbridge and W. B. Truesdell*, 289.

Photometry, On the Growth and Decay of Color Sensations in Flicker, *M. Luckiesh*, 1.

Platinum, The Vapor Pressure of the Metals, and Molybdenum, *Irving Langmuir and C. M. J. Mackay*, 377.

Pondermotive Force, upon a Dielectric which Carries a Displacement Current in a Magnetic Field, *Robert H. Goddard*, 99.

Pyrometer Method, The Thermal Conductivities of Tungsten, Tantalum and Carbon at Incandescent Temperatures by an Optical Pyrometer Method, *A. G. Worthing*, 535.

Q.

Quartz Fibers, On the Silvering of, by the Cathode Spray, *Horatio B. Williams*, 517.

R.

Radiometers, Stellar, A Comparison of, and Radiometric Measurements on Stars, *W. W. Coblentz*, 545.

Radiotransmission, Diurnal and Annual Variations in Overland, *A. H. Taylor*, 435.

Raman, C. V., The Maintenance of Vibrations 12.

Rectification, Characteristics of Contact, with a Silicon Carbon Contact, *Ralph C. Hartsough*, 306.

Residual Gases, The Effect of, on Contact E.M.F.'s and Photo-Currents, *R. A. Millikan and W. H. Souder*, 73.

Resistance of Metals, The Temperature Coefficient of, at Constant Volume and Its Bearing on the Theory of Metallic Conduction, *Charles A. Kraus*, 159.

Richardson, O. W., Note on the Direct Determination of *h*, 522.

Roentgen Radiation, The Factors which Determine the Quantity of, given off by an X-Ray Tube, *Wheeler P. Davey*, 208.

S.

Selenium, The Crystal Forms of Metallic, and Some of their Physical Properties, *F. C. Brown*, 85.

Selenium, The Influence of Annealing on the Characteristics of Light Sensitive, *E. O. Dieterich*, 467.

Selenium Resistance, The Time Factor in, *G. E. Grantham*, 259.

Selenium, Wave-length-Sensibility Curves for Light Sensitive, and their Significance, *F. C. Brown and L. P. Sieg*, 48.

Selenium, Wave-Length-Sensibility Curves of Certain Crystals of Metallic, and a Partial Explanation of the Complexity of Light-Action in Selenium Cells, *L. P. Sieg and F. C. Brown*, 507.

Sheard, Charles, Dioptric Formulae for Cylindrical Lenses Combined at Oblique Axes, 274.

Sherman, Geo. W., Jr., A Study of the Magnetic Qualities of Stressed Iron and Steel, 267.

Sieg, L. P., Wave-Length-Sensibility Curves of Certain Crystals of Metallic Selenium; and a Partial Explanation of the Complexity of Light-Action in Selenium Cells, 507.

Wave-Length-Sensibility Curves for Light Sensitive Selenium and their Significance, 48.

Silicon, The Hall Effect and Allied Pheonomena in, *O. E. Buckley*, 482.

Silsbee, F. B., Methods of Measuring Time Constants of Low Resistances, 71.

Similitude, The specific Heat of Solids and the Principle, of, *Richard Chace Tolman*, 145.

Simpson's Rule, Some Applications of, in Integrating Periodic Functions, *Frederick Bedell and Ralph Bown*, 548.

Smith, C. M., A Study of the Magnetic Qualities of Stressed Iron and Steel, 267.

Souder, W. H., The Effect of Residual Gases on Contact E.M.F.'s and Photo-Currents, 73.

Spark Potentials, The Effect of a Longitudinal Magnetic Field on, *Robert F. Earhart*, 135.

Specific Heats, The, of Mixtures of Alcohol and Water and of Solutions of Non-electrolytes in these Mixtures, *William Francis Magie*, 287.

Spectrophotometric, A Study of the Absorption, Fluorescence, and Surface Color of Magnesium Platinum Cyanide, *Frances G. Wick*, 561.

Stark Effect, The Transverse, upon Aluminum Doublets, *Reinhard A. Wetzel*, 550.

Steel, A Study of the Magnetic Qualities of Stressed Iron and, *C. M. Smith and Geo. W. Sherman, Jr.*, 267.

Stefan-Boltzman Law, High Temperature Measurements with the, *C. E. Mendenhall and W. E. Forsythe*, 62.

Stewart, G. W., Phase Relations in the Acoustic Shadow of a Rigid Sphere; Phase Difference at the Ears, 252.

Stressed Iron, A Study of the Magnetic Qualities of, and Steel, *C. M. Smith and Geo. W. Sherman, Jr.*, 267.

Stuhlmann, Jr., Otto, On the Asymmetric Emission of Photo-Electrons from Thin Films of Platinum, I, 195.

T.

Taylor, A. H., Diurnal and Annual Variations in Overland Radiotransmission, 435.

Temperature Distribution in an Incandescent Lamp Filament in the Neighborhood of a Cooling Junction, *A. G. Worthing*, 524.

Thermal Conductivities, The, of Tungsten, Tantalum and Carbon at Incandescent Temperatures by an Optical Pyrometer Method, *A. G. Worthing*, 535.

Thermal Energy, The Distribution of, *Gilbert N. Lewis and Elliot Q. Adams*, 331.

Thermionic Currents, Determination of e/m from Measurements of *Saul Dushman*, 121.

Time Constants, Methods of Measuring, of Low Resistances, *Frank Wenner, Ernest Weibel, and F. B. Silsbee*, 71.

Tolman, Richard Chace, The Specific Heat of Solids and the Principle of Similitude, 145.

Trowbridge, C. C., Measurements with a Moving Lamp Photometer, 289.

Truesdell, W. B., Measurements with a Moving Lamp Photometer, 289.

Turbidimeter, A New, *P. V. Wells*, 396.

V.

Vapor Pressure, The, of the Metals Platinum and Molybdenum, *Irving Langmuir and C. M. J. Mackay*, 377.

Vibrations, The Maintenance of, *C. V. Raman*, 12.

Volta Effect, On the Nature of the, *Albert E. Hennings*, 247.

W.

Waltenberg, R. G., The Emissivity of Metals and Oxides, II: Measurements with the Micropyrometer, 546.

Wave-Length-Sensibility Curves for Light Sensitive Selenium and their Significance, *F. C. Brown and L. P. Sieg*, 48.

Webster, David L., The Effect of Pressure on the Absorption of Light by Bromine and Chlorine, and its Theoretical Significance, 177, 561.

Weibel, Ernest, Methods of Measuring Time Constants of Low Resistances, 71.

Wells, P. V., A New Turbidimeter, 396.

Wendt, George, The Electric Resolution of the Series Lines in the Mercury Spectrum, 549.

Wenner, Frank, Methods of Measuring Time Constants of Low Resistances, 71.

Wetzel, Reinhard A., The Electric Resolution of the Series Lines in the Mercury Spectrum, 549.

The Transverse Stark Effect upon Aluminum Doublets, 550.

Wick, Frances G., A Spectrophotometric Study of the Absorption, Fluorescence, and Surface Color of Magnesium Platinum Cyanide, 561.

Williams, Horatio B., On the Silvering of Quartz Fibers by the Cathode Spray, 517.

Williams, S. R., An Achromatoscope, 550.

A Comparison of the Longitudinal and Transverse Joule Magnetostrictive Effects in the Same Specimens of Steel and Nickel, 498.

The Villari Critical Point in Ferromagnetic Substances, 288.

Worthing, A. G., Temperature Distribution in an Incandescent Lamp Filament in the Neighborhood of a Cooling Junction, 524.

The Thermal Conductivities of Tungsten, Tantalum and Carbon at Incandescent Temperatures by an Optical Pyrometer Method, 535.

Some Effects of Diffraction on Brightness Measurements made with the Holborn-Kurlbaum Optical Pyrometer, 163.

Woodrow, J. W., Experiments on the Production and Measurement of High Vacua, 491.

X.

X-Rays, The Mean Depth of Formation of, in a Platinum Target, *Laura G. Davey*, 217.

VOLUME IV SECOND SERIES NUMBER 6

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DECEMBER, 1914

A Contrast Equality Photometer. A. H. PFUND 477

The Hall Effect and Allied Phaenomena in Silicon. O. E. BUCKLEY 482

Experiments on the Production and Measurement of High Vacua. J. W. WOODROW 491

A Comparison of the Longitudinal and Transverse Joule Magnetostrictive Effects in the Same Specimens of Steel and Nickel. S. R. WILLIAMS 498

Wave-Length Sensibility Curves of Certain Crystals of Metallic Selenium; and a Partial Explanation of the Complexity of Light-Action in Selenium Cells. L. P. SIEG and F. C. BROWN 507

On the Silvering of Quartz Fibers by the Cathode Spray. HORATIO B. WILLIAMS 517

Note on the Direct Determination of h. O. W. RICHARDSON 522

Temperature Distribution in an Incandescent Lamp Filament in the Neighborhood of a Cooling Junction. A. G. WORTHING 524

The Thermal Conductivities of Tungsten, Tantalum and Carbon at Incandescent Temperatures by an Optical Pyrometer Method. A. G. WORTHING 535

Proceedings of the American Physical Society. 544

Minutes of the Seventy-Third Meeting: A Comparison of Stellar Radiometers and Radiometric Measurements on Stars, *W. W. Coblentz;* The Emissivity of Metals and Oxides, II: Measurements with the Micropyrometer *C. K. Burgess and R. G. Waltenberg;* Electrostatic Measurement of Single Electrode Potentials, *A. W. Ewell;* Some Applications of Simpson's Rule in Integrating Periodic Functions, *Frederick Bedell and Ralph Brown;* The Electric Resolution of the Series Lines in the Mercury Spectrum, *George Wendt and Reinhard A. Wetzel;* The Transverse Stark Effect upon Aluminum Doublets, *Reinhard A. Wetzel;* The Total Emissivity of Platinum and the Relation between Total Emissivity and Resistivity, *Paul D. Foote;* An Achromatoscope, *S. R. Williams.*

New Books. 558

Errata and Addenda 561

Index 562

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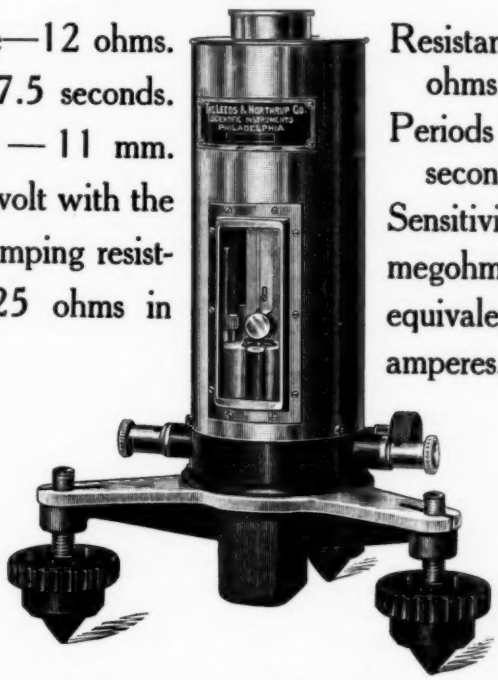

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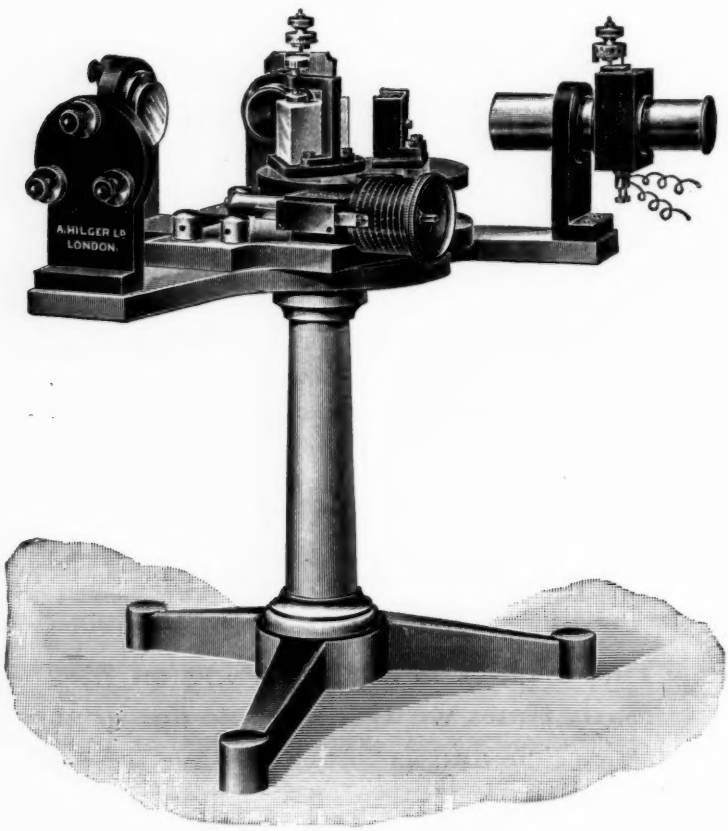

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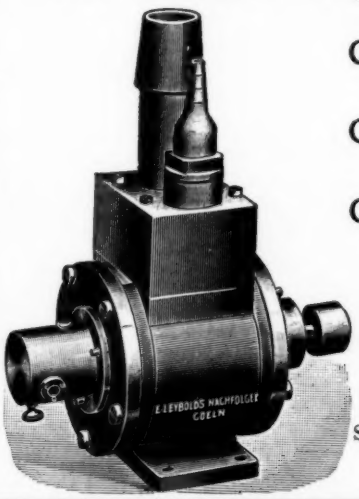

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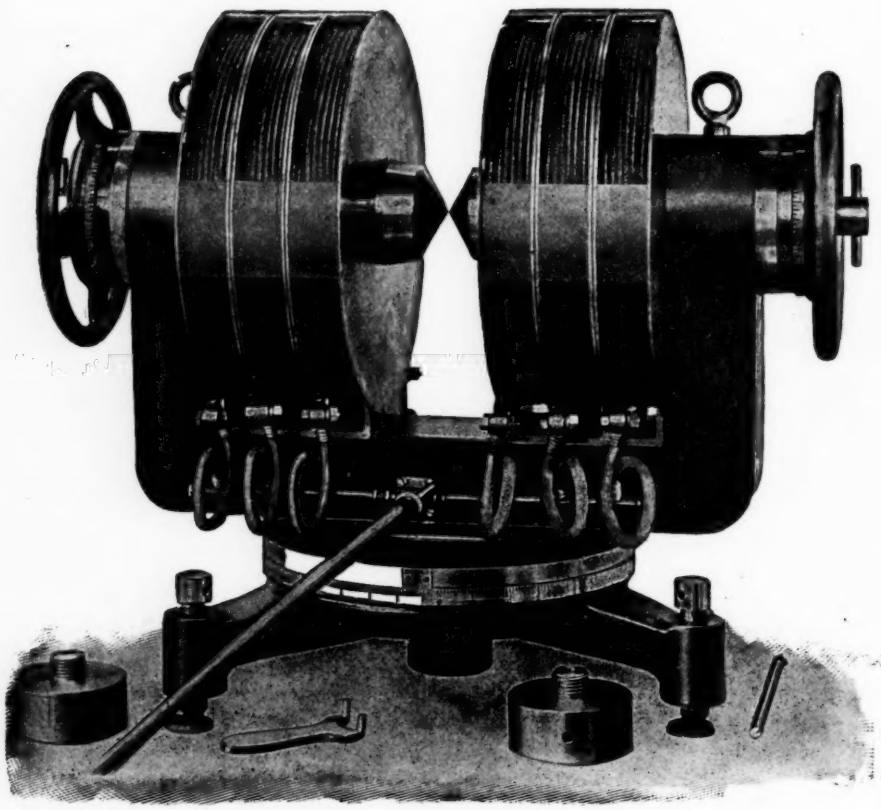

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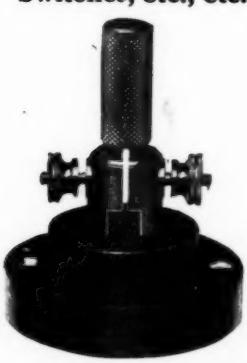

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